March 2009

ENVIRONMENT CANADA'S HIGH ARCTIC WEATHER STATION EUREKA, NUNAVUT

INVESTIGATION OF WASTEWATER TREATMENT OPTIONS

Submitted to:
Public Works and Government Services Canada
Environmental Services, Western Region
5th Floor, Telus Plaza North
10025 Jasper Avenue, Edmonton, AB
T5J 1S6

REPORT

Report Number: 09-1125-0005

Distribution:

5 copies - PWGSC
1 e-copy - PWGSC
2 copies - Golder Associates Ltd.

Golder Associates

Executive Summary

Golder Associates Ltd. (Golder) was retained by Public Works and Government Services Canada (PWGSC) to identify suitable alternatives to upgrade the wastewater treatment infrastructure at Environment Canada's (EC's) High Arctic Weather Station (HAWS) in Eureka, Nunavut.

Flow information from 2007 and 2008 was evaluated including water balances on the water reservoir and sewage lagoon. A design flow of 12.4 m^3/d was selected based on the maximum month flow in 2007 and 2008.

Several wastewater treatment technologies were considered for use at Eureka, including:

1. conventional activated sludge with separate clarifier;
2. integrated activated sludge and clarifier;
3. sequencing batch reactor (SBR);
4. rotating biological contactor (RBC);
5. media-based tricking filter;
6. submerged fixed film bioreactor; and,
7. new 2-cell facultative lagoon.

The technologies were evaluated compared based on the following ranking criteria: treatment performance, ease of operations, risk and impact of process upset, risk and impact of mechanical failure, energy consumption, capital cost, and sludge handling and disposal requirements. Based on these rankings, three technologies were short-listed: media-based trickling filter, submerged fixed film bioreactor, and new 2-cell lagoon.

Conceptual site and installation plans were developed for the short listed technologies. Two location options were provided for the new lagoon. Two years would be required for installation of a submerged fixed film bioreactor or a media-based tricking filter, whereas the new lagoon would likely require three years for installation.

Detailed cost estimates were provided for the short listed technologies, including both initial capital costs and lifecycle costs. The lifecycle costs were estimated using the net present value (NPV) after 20 and 40 years, with an inflation rate of 2% and an interest rate of 4%.

Technology	Initial Cost	NPV after 20 Years	NPV after 40 Years
Media-based Trickling Filter*	$1,867,906	$2,704,399	$3,105,792
Submerged Fixed Film Bioreactor*	$2,127,619	$2,169,894	$2,388,418
Lagoon Option 1*	$2,781,187	$2,968,549	$3,077,430
Lagoon Option 2*	$3,157,824	$3,349,187	$3,482,438

Approximate costs were also provided for other technologies for comparative purposes.

Sludge handling requirements will depend on which treatment option is selected. A very simple drying bed is recommended to provide passive dewatering and sludge stabilization. The drying bed can be constructed in the active layer using equipment available on site.

Three effluent disposal options were considered, including year round discharge to the fjord to a submerged outfall, year round discharge to the fjord using an elevated outfall, or effluent storage and seasonal discharge. If the existing sewage lagoon can be converted to an effluent storage lagoon, seasonal discharge would be the most economical option.

Effluent monitoring recommendations are provided based on the site's existing monitoring requirements. On-site testing should be considered for parameters that have holding time restrictions.

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 Objectives and Scope of Work

Golder Associates Ltd. (Golder) was retained by Public Works and Government Services Canada (PWGSC) to identify suitable alternatives to upgrade the wastewater treatment infrastructure at Environment Canada's (EC's) High Arctic Weather Station (HAWS) in Eureka, Nunavut. The site is located on Ellesmere Island, in the Qikiqtaaluk (Baffin) Region of Nunavut (refer to Figure 1, Key Plan). An aerial photograph of the site is included in Figure 2.

Golder's scope of work included the following tasks:

- Investigate the current water consumption and wastewater production of the facility (mass balance),
- Present recommendations for potential on-site wastewater treatment options,
- Present recommendations for real-time effluent monitoring and discharge into the fjord in all weather conditions and/or holding tank options for adverse or seasonal weather conditions,
- Present recommendations for handling and disposal of remainder sludge, and
- Present recommendations for decommissioning of the current sewage lagoon system and associated components.

The recommended treatment options must be suitable for use in the challenging weather conditions in Eureka, account for the limited availability of water and electricity, be field maintainable by on-site personnel with limited training and be scalable to handle fluctuations in population. As much as possible, existing infrastructure was to be incorporated into the recommended treatment system.

1.2 Site Background

Several government departments and other agencies operate on the Environment Canada Land Reserve at Eureka, NU. The main camp is operated by Environment Canada. The Department of National Defence (DND), Polar Continental Shelf Project and Ken Borek Air all operate facilities at the Eureka airport. The Polar Environment Atmospheric Research Laboratory (PEARL) is owned by Environment Canada and operated by CANDAC which is a partnership between universities and agencies involved in Atmospheric Studies. This lab is located approximately 13 km from the main camp.

Potable water is pumped to a reservoir from Station Creek in the summer and is withdrawn and treated as needed on a year round basis. All raw water is treated using chlorination. Water treated by reverse osmosis is also available in the kitchen and washrooms of the Main Complex.

Currently, wastewater from the Main Complex flows to a holding tank in the pump house. When the tank is full it is pumped to a single-cell sewage lagoon for storage and primary treatment. The effluent is discharged to Slidre Fjord in the summer months. The Nunavut Water Board has indicated that the current lagoon is located too close to Slidre Fjord. EC would like to discontinue use of the existing lagoon for wastewater treatment. Any future wastewater treatment facility at Eureka will need to be designed to handle wastewater from the

Environment Canada complex, Polar Continental Shelf, Ken Borek Air and PEARL. DND draws water from the water reservoir for use at Fort Eureka, but the wastewater generated is treated in a separate lagoon near the fort. A small amount of water is used at the PEARL Lab, Polar Continental Shelf Project facility and Ken Borek facility but waste is trucked back to be treated in EC's lagoon.

Wastewater discharges in Nunavut are regulated by the Nunavut Water Board (NWB). Environment Canada has a licence from the NWB dated February 6, 2006 that regulates the use of water, disposal of waste (including wastewater), and the handling and storage of petroleum products or hazardous materials. Because the weather station is a federal facility, additional guidance is provided by "An Approach for Assessing and Managing Wastewater Effluent Quality for Federal Facilities", published by Environment Canada in June 2001.

2.0 REVIEW OF WATER CONSUMPTION AND WASTEWATER VOLUMES

2.1 Water Balance

A water balance was completed for the Site to identify inconsistencies. Each year, water is pumped from Station Creek into the freshwater reservoir onsite. The water is then consumed at Eureka and Fort Eureka. Wastewater is pumped via a pumping station to the sewage lagoon, where, once a year it is pumped into Slidre Fjord. For the purposes of the water balance the following assumptions have been made:

- Pumping from Station Creek to the freshwater reservoir occurs near the end of June or the beginning of July each year;
- Pumping from the sewage lagoon to Slidre Fjord occurs near the end of June or the beginning of July each year;
- The freshwater reservoir is filled to the same level each year;
- The sewage lagoon is emptied to the same level each year;
- All water consumed at the EC Main Complex, PEARL, Polar Shelf and Ken Borek is ultimately discharged to the wastewater lagoon;
- Water consumed by DND is treated separately and is therefore not included in the input to the sewage lagoon; and,
- All water consumed by EC is ultimately directed to the wastewater lagoon.

The pumping and consumption data was provided by EC. Precipitation data was obtained from EC's Weather Office for the Eureka meteorological station. An annual average evaporation of 100 millimetres per year was obtained from the Hydrologic Atlas of Canada (Department of Fisheries and the Environment, 1975).

The Site was separated into two bodies of water for the water balance: the freshwater reservoir and the sewage lagoon. The inputs to the freshwater reservoir are the freshwater pumped from the creek and precipitation, while the outputs are total water consumed and evaporation. The inputs to the sewage lagoon are the EC water consumed and precipitation, while the outputs are the waste water discharged and evaporation. The water balance was completed for the period from July 2006 to June 2007 and from July 2007 to June 2008. The results of the water balances are provided in the Table 1.

Table 1: Water Balance

Year	Body of Water	Inputs	Outputs	Error
2007 (July 2006 - June 2007)	Freshwater Reservoir	2,687 m^3	2,834 m^3	5%
	Sewage Lagoon	1,636 m^3	1,541 m^3	- 6%
2008 (July 2007-June 2008)	Freshwater Reservoir	3,284 m^3	3,433 m^3	4%
	Sewage Lagoon	2,157 m^3	1,534 m^3	- 29%

Small deviations of around 5 to 10% are not unusual and can be attributed to method of measurement (metered, water level changes etc.), accuracy of measuring device, frequency of measurement, and varying timeframes of measurement. The differences between water and sewage volumes (water outputs compared to sewage inputs) of -42% and -37% for years 2007 and 2008, respectively are associated with the consumption by DND. The difference of -29% in the sewage input volume to output volume in the year 2008 could also be explained by the above factors but could also be increased infiltration into the underlying unfrozen soils below the unlined lagoons.

Based on the variability and significant increase in water consumption between 2007 and 2008, a closer examination of the measurement methods and tools is recommended. It is important to confirm if the deviations represent real conditions that are causing losses of water or if the data quality needs improvements through better measuring methods.

2.2 Review of Flows and Wastewater Quality

Water consumption data was available for the weather station for several years (2001-2008). The annual flow rate varied from 1,163 to 2423 m^3/year (flows to Fort Eureka are excluded as the wastewater is treated separately). The year with the highest flow was 2008.

We understand from EC that any future wastewater treatment system for Eureka should be designed to treat the flow from 2008 with a 20% safety factor, as site activities are expected to be maintained or reduced in the coming years. We have therefore selected treatment options suitable for treating an average day flow of 12.4 m^3/d (based on the water demand in the largest month). A maximum day flow of 24.8 m^3/d was estimated using a peaking factor of 2 over the average day flow. A peak hourly flow of 2.06 m^3/h was estimated using a peaking factor of 4 over the average day flow.

More detailed data was available in 2008, including more frequent water demand measurements (weekly at a minimum) and station population daily. This information was used to determine an average flow per capita per day. The average flow per capita per day varies considerably, with a minimum of 196 L/capita/day in November, and a maximum of 565 L/capita/day in July with an average of 325 L/capita/day. Typically, the wastewater flow to a domestic wastewater treatment plant is between 150 and 500 L/capita/day with an average of 230 L/capita/day. The Eureka flows are in the range closer to higher end in comparison.

Raw wastewater quality information was not available. However, based on the flow per capita per day, a low to medium strength wastewater can be expected. The preliminary design for wastewater treatment options has been carried out on the basis of high strength waste to ensure that the treatment system will remain suitable if aggressive water saving measures are adopted. Typical raw wastewater quality for low, medium and high strength wastewater is included in Table 2 for reference. Samples of the raw wastewater should be analyzed prior to design of the selected treatment system to assess the raw wastewater quality.

Table 2: Typical Raw Wastewater Quality for Domestic Waste

Parameter	Low strength	Medium Strength	High Strength
Total suspended solids (TSS) – mg/L	120	210	400
Biochemical oxygen demand (BOD_5) – mg/L	110	190	350
Nitrogen (total) – mg/L	20	40	70
Nitrogen (organic) – mg/L	8	15	25
Nitrogen (free ammonia) – mg/L	12	25	40
Total phosphorus – mg/L	4	7	12
Oil and grease – mg/L	50	90	100
Fecal coliform – No./100 mL	10^3-10^5	10^4-10^6	10^5-10^8

(adapted from Metcalf and Eddy, p186)

3.0 REVIEW OF WASTEWATER TREATMENT OPTIONS

3.1 Methodology

The following steps were carried out with the objective of identifying a short list of wastewater treatment technologies suitable for further consideration for use at Eureka:

1) Wastewater treatment technology options were identified that were considered likely candidates to meet EC's stated requirements for use at Eureka (see Section 3.2).
2) Information was gathered for each treatment technology based on Golder's experience, information from technology suppliers and technical reference material (see Section 3.3).
3) Technology ranking criteria were developed based on communications with PWGSC and EC (see Section 1.1).
4) Each ranking criteria was assigned a weighting based on its relative importance for Eureka (see Section 3.6).
5) The technologies were then scored comparatively for each ranking criteria. The weighted scores were tabulated to identify the short list of technologies for further consideration (see Section 3.6).

3.2 Identification of Wastewater Treatment Technologies for Consideration

A variety of wastewater treatment technologies were considered for use at Eureka, including:

1) Conventional activated sludge (AS) with separate clarifier;
2) Integrated activated sludge (AS) and clarifier;
3) Sequencing batch reactor (SBR);
4) Rotating biological contactor (RBC);
5) Media-based trickling filter;
6) Submerged fixed film bioreactor; and,
7) New 2-cell facultative lagoon.

Each of these technologies is described below are available for site specific design or available as a package from various suppliers. The main advantages and disadvantages of each technology are highlighted.

3.3 Technology Descriptions

Each of the technologies is described below, and the key advantages and disadvantages are highlighted. Additional information about each technology is provided in the technology ranking rationales provided in Sections 1.1, below.

3.3.1 Conventional Activated Sludge with Separate Clarifier

The basic activated sludge process includes three process components: (1) an aerated bioreactor which maintains suitable conditions for the biological degradation of organic contaminants in the wastewater, (2) a liquid-solid separation, which is typically achieved by settlement of solids, and (3) a recycle stream which returns a portion of the solids (including the bacteria responsible for treatment) from the solid-liquid separation back to the bioreactor. The basic process is illustrated in Appendix B.

Conventional activated sludge treatment systems provide treatment for BOD and TSS. Process upgrades are available to treat for several additional parameters. Upgrades may involve additional tanks, additional recycle lines, and chemical addition.

The activated sludge process was developed in the late 1800s and early 1900s, and many process modifications have evolved to address differing wastewater characteristics and flows, and to meet more stringent effluent criteria. Conventional activated sludge treatment systems form the basis for a large percentage of municipal treatment systems in Canada, and many smaller scale adaptations are available.

Table 3 provides a summary of the characteristics of a conventional activated sludge treatment system for comparison with the other options under consideration. The scores for each ranking criterion are provided in Section 3.5, along with a brief explanation of the rationale for each score.

3.3.2 Integrated Activated Sludge and Clarifier

This process is similar to the conventional activated sludge system, but the aeration and clarification steps take place in the same unit to provide a more compact design and reduce sludge handling requirements.

The Whitewater® treatment system is an example of this technology. This is a proprietary system by Delta Environmental Products Inc. that was developed to treat relatively low flows. Pre-treatment is provided by a conventional septic tank. The main process tank contains a conical clarifier supported within it. The area between the clarifier and the outside of the tank is aerated. Wastewater enters into the aeration zone, and then flows up into the clarifier as a result of the flow regime within the tank. The clear water rises to the top of the clarifier, and is removed via the effluent pipe. The solids settle to the bottom of the clarifier within in the aeration zone, where they are remixed into suspension to provide treatment. The Whitewater process is described in a brochure included in Appendix B.

The Whitewater® system treats effectively for BOD and TSS. Some total nitrogen removal is achieved as a result of the cycling of the wastewater through the aeration and (anoxic) settling zone.

Table 3 provides a summary of the characteristics of an integrated activated sludge and clarifier for comparison with the other options under consideration. The scores for each ranking criterion are provided in Section 3.5, along with a brief explanation of the rationale for each score.

3.3.3 Sequencing Batch Reactor (SBR)

A sequencing batch reactor (SBR) is a fill and draw activated sludge treatment system. It has five common steps which are fill, aerate, settle, draw and idle. Additional information about the SBR process is included in Appendix B. The unit processes with a SBR are very similar to activated sludge treatment. The most important advantage is that it carries out aeration, sedimentation and clarification in the same tank rather than separate tanks. Two reactor units are often used, so that one unit fills while the other is cycling through the treatment stages. SBRs are efficient in removing organics and suspended solids. The effluent quality is directly related to the effectiveness of the decanting and aeration. Total nitrogen can be partially treated with adjustments to the process operating sequence.

SBRs are typically implemented for larger flow rates than can be expected at Eureka, although there are several suppliers that offer smaller scale units. For the purpose of the technology comparison for Eureka, we have used information from Napier-Ried Ltd. If a SBR is selected for use at Eureka, there are several manufacturers and suppliers that could be considered.

Table 3 provides a summary of the characteristics of SBRs for comparison with the other options under consideration. The scores for each ranking criterion are provided in Section 3.5, along with a brief explanation of the rationale for each score.

3.3.4 Rotating Biological Contactor (RBC)

Rotating biological contactors (RBC) consist of a series of closely spaced disks on a shaft. The disks are partially submerged in wastewater and are slowly rotated through the wastewater. The disks support a biologically active film of aerobic microorganisms which biodegrade organic pollutants. The portion of the disks that is above the wastewater is passively aerated as the disks rotate, although some designs also include submerged aerators. Excess biomass from the disks shears off at the disks rotate, and settles at the bottom of the treatment tank. The solids can then be removed. For ultimate performance efficiency, an RBC should be combined with adequate primary treatment to remove settleable solids and a secondary clarifier to concentrate biological sludge from the RBC unit. Appendix B includes information about an example RBC unit from Seprotech (Rotordisk®).

With pre- and post-treatment, RBCs can remove BOD and TSS. Nitrification and de-nitrification can be provided with additional process components.

The first full scale installation of RBCs was in Germany in the 1960s. Since then, the media type and equipment configuration have been refined, and currently there are thousands of these units in operation worldwide. RBCs have also been installed successfully in cold climates with proper insulation and heating where necessary. RBC units can maintain treatment efficiency for wastewater temperatures greater than 13°C; for temperatures between 5 and 13°C more media surface area is required to achieve same performance.

There are many manufacturers available for RBC units. Although the basic process is the same with each product, the pre- and post-treatment options may vary considerably, and the RBC unit itself may be configured slightly different or use a different media. For the purpose of the technology comparison at Eureka we have used information from Seprotech Systems Inc. If an RBC unit is selected for use at Eureka, there are numerous manufacturers and suppliers that could be considered.

Table 3 provides a summary of the characteristics of a RBC with the other options under consideration. The scores for each ranking criterion are provided in Section 3.5, along with a brief explanation of the rationale for each score.

3.3.5 Media-based Trickling Filter

Media-based trickling filters are a type of trickling filter that uses a specialized media for treatment. As for other trickling filters, in a media-based trickling filter the wastewater is distributed across the top of the treatment media. The media remains partially saturated, and the wastewater gradually flows through around and through the porous media. Aerobic conditions are maintained by a low power fan that circulates air through the filter. Treatment is provided by a biofilm of aerobic bacteria that develops on the media's internal pores and external surface.

The Waterloo Biofilter® is an established example of a package media-based trickling filter that is patented by Waterloo Biofilter Systems Inc. Settleable solids and floatables are removed in a pre-treatment septic tank with an effluent filter. In the trickling filter unit, the wastewater is sprayed over the absorbent synthetic filter medium and is drained by gravity. The filter medium has a high porosity for maximum air flow, and a large surface area on which the biomass can develop. Additional information from Waterloo Biofilter is included in Appendix B.

The system removes BOD and TSS.

Waterloo Biofilter has installation in many remote and cold climates. They are able to provide all treatment components installed in shipping containers for very simple installation onsite.

Table 3 provides a summary of the characteristics of media-based trickling filters with the other options under consideration. The scores for each ranking criterion are provided in Section 3.5, along with a brief explanation of the rationale for each score.

3.3.6 Submerged Fixed Film Bioreactor

Activated sludge processes can also incorporate fixed media that allow surfaces for attached growth or film similar to RBC units. Fixed film bioreactor systems require a considerably smaller treatment volume as compared with basic activated sludge systems.

Fixed Activated Sludge Treatment (FAST®) system is an established example of packaged system patented by Bio-Microbics Inc. The FAST® technology is distributed in Canada is through Pinnacle Environmental Technologies Inc. Additional information about FAST® technology is included in Appendix B.

FAST treatment systems were originally invented to meet the challenges of shipboard use. The technology has now been adapted for use for residential, commercial, municipal, industrial and marine applications. Pinnacle Environmental has installed several systems in arctic conditions.

With a standard FAST system, an initial chamber removes solids and floatables much like a conventional septic tank. A second chamber has a fixed film media area with vigorous aeration from a blower to remove BOD and total nitrogen.

Table 3 provides a summary of the characteristics of submerged fixed film bioreactors with the other options under consideration. The scores for each ranking criterion are provided in Section 3.5, along with a brief explanation of the rationale for each score.

3.3.7 New 2-cell Facultative Lagoon

Lagoons are earthen holding basins where waste stabilization and pathogen die off occur naturally. Lagoons are generally classified as anaerobic, facultative or aerobic. Facultative lagoons are most commonly used, as they combine the process advantages of both anaerobic and aerobic lagoons. On upper layers with the help of larger surface area aerobic digestion takes place and at lower depths the reactions will be anaerobic.

With a lagoon system, the rates of reaction in the lagoon are directly influenced by ambient temperature. During winter months which are extended in arctic climates, the biological treatment processes in the lagoons drop to a minimal level due to ambient temperature that slows biological activity. Therefore the majority of the treatment takes place only in the summer months; however, freezing can separate out suspended solids which include a high percentage of the chemical oxygen demand (COD). The limited period for treatment (two to three months of the year) results in an increase in lagoon dimensions and aeration requirements to meet effluent quality criteria.

Lagoon design is not included with this assessment. For the purposes of this assessment, we have assumed that a two cell facultative lagoon with a depth of 3 metres will be installed. Each cell has been sized to hold 1 year of wastewater from the site. A liner has been included for both cells.

Table 3 provides a summary of the characteristics of 2-cell facultative lagoons with the other options under consideration. The scores for each ranking criterion are provided in Section 3.5, along with a brief explanation of the rationale for each score.

3.4 Technology Summary Table

Table 3 provides a summary of the characteristics of each technology considered.

Table 3: Technology Summary Table

Technology	Treatment Performance	Ease of Operation	Risk and Impact of Process Upset	Risk and Impact of Mechanical Failure	Energy Consumption (Heating and Electricity)	Capital Cost	Sludge Handling and Disposal Requirements
Activated Sludge with Separate Clarifier	• < 30 mg/L effluent BOD and TSS • Operating temperature > 10°C	• Moderate maintenance • Recommended monthly checks for compressors, pumps, floats and control panels • Controls may require adjustment to optimize system at various flow rates	• Can handle receiving grease or high organic loads without major problems • Process tanks could be flushed if required (in case of toxic material entering treatment system)	• Air blower or pump failure possible • Blower or pump failure could be resolved with onsite staff and spare parts	• Indoor heating is required for moderate-sized building • Electricity required for pumps and blowers for aeration (max. draw for all elements approx. 170 kW/h) • Main power consumption is from blower operating full time	• Estimated initial system cost is $2.0 mil	• Regular sludge removal from clarifier is required (daily or weekly basis)
Activated Sludge with Integrated Clarifier (such as Whitewater)	• < 30 mg/L effluent BOD and TSS • <10 mg/L TN • Operating temperature > 10ºC	• Low maintenance • Air filter need to be replaced every 6 months	• Can handle receiving grease or high organic loads without major problems • Process tanks could be flushed if required (in case of toxic material entering treatment system)	• Air blower or pump failure possible • Blower or pump failure could be resolved with onsite staff and spare parts	• Indoor heating is required for relatively small building • Electricity required for air blower and pumps (max. draw for all elements approx. 170 kW/h) • Main power consumption is from blower operating full time	• Estimated initial system cost is $2.1 mil	• Pretreatment septic tank should be emptied of sludge every 1-3 years • Sludge production in the treatment unit is minimal
Sequencing Batch Reactor (SBR)	• < 10 mg/L effluent TSS and BOD concentrations • 5-8 mg/L TN • Operating temperature > 7ºC	• Higher level of operation and maintenance required due to controls, aeration devices, pumps, valves, automated switches. • Requires daily check (~1 h)	• If SBR process was upset, restart could require visit from skilled operator (complex process control system) • Effluent quality depends upon reliable decanting and aeration devices and stable influent quantity and quality	• Air blowers, pump or control panel failure possible • Blower or pump failure could be resolved with onsite staff and spare parts • Controls failure could require technical support to come to Eureka	• Indoor heating is required for relatively small building • Electricity required for pumps, blowers and control units (max. draw for all elements approx.30 kW/h) • Main power consumption is from blowers operating intermittently (approx. 35-65% of the time)	• Estimated initial system cost is $1.8 mil	• Regular sludge removal from treatment tank is required (daily or weekly basis)
Rotating Biological Contactor (RBC)	• < 30 mg/L effluent TSS and BOD concentrations • Operating temperature > 10-15ºC	• Low maintenance • Simple drive and bearing lubrication monthly • Check bearings once a year • Change bearing motor every 10 years • Controls may require adjustment to optimize system at various flow rates	• Fixed film resistant to kill off with changes in flowrate or influent quality • If process upset, could likely be resolved by onsite operator (spray off discs and restart)	• Shaft, bearing or pump failure possible • Pump failure could be resolved with onsite staff and spare parts • Shaft failure would require new unit to be shipped to Eureka (could require airlift or waiting for sealift the following fall)	• Indoor heating is required for relatively large building • Electricity required for motor and pumps (max. draw for all elements approx. 18 kW/h) • Low energy consumption (3 kW per 3,000 people according to Siemens) • Main power consumption is from motor rotating shaft	• Estimated initial system cost is $2.2 mil	• Regular sludge removal from RBC basin is required (weekly or monthly basis)
Media Based Trickling Filter	• < 30 mg/L effluent TSS and BOD concentrations • Operating temperature > 8ºC	• Low maintenance • Filter medium normally does not require cleaning or changing (expected life span is 20-30 years) • Recommended monthly checks includes effluent filters, spray nozzles, biofilter medium, all pumps, floats and control panels.	• Designed for peak daily flow but can operate with little or no flow with no reduction in treatment when the flow rates increase • Vulnerable to process upset by grease in filter (would coat media); would have to replace media (shipped from the south)	• Pump or air fan failure possible • Pump or fan failure could be resolved with onsite staff and spare parts	• Indoor heating is required for moderate-sized building • Electricity required for fan, pumps (max. draw for all elements approx. 9 kW/h) • Main power consumption is from pumps	• Estimated initial system cost is $1.9 mil	• Pretreatment septic tank should be emptied of sludge every 1-3 years • Treatment unit does not produce sludge
Submerged Fixed Film Bioreactor (such as FAST System)	• More than 90% removal of TSS, BOD • Operating temperature > 10-15ºC	• Low maintenance • Every 3 months air filter should be cleaned	• Fixed film resistant to kill off with changes in flowrate or influent quality • If process upset, could likely be resolved by onsite operator (spray off discs and restart)	• Air blower or pump failure possible • Blower or pump failure could be resolved with onsite staff and spare parts	• Indoor heating is required for relatively large building • Electricity required for air blower and pumps (max. draw for all elements approx. 170 kW/h) • Main power consumption is from blower operating full time	• Estimated initial system cost is $2.1 mil	• Pretreatment septic tank should be emptied of sludge every 1-3 years • Sludge production in the treatment unit is minimal (residue must be pumped every 3-5 years)
New Lagoon (2-cell facultative)	• < 100 mg/L effluent BOD and TSS • Performance for a new 2-cell lagoon would be significantly higher than existing lagoon	• Low maintenance during year • In summer months, a larger amount of attention would be required to discharge and transfer cell contents • May require berm repairs periodically (every 5-10 years)	• Can handle changes in influent quality and quantity very well (large buffering capacity)	• Pump failure • Pump failure could be resolved with onsite staff and spare parts • Pumps used seasonally only, so receive less wear than with other options	• No indoor heating is required • Electricity required for pumps (only required in summer season for effluent disposal and transfer between cells) (max. draw for all elements approx. 0.5 kw/h) • Main power consumption is for heat tracing to lagoon site	• Estimated initial system cost is $2.8 mil for location option 1, or $3.2 mil for location option 2	• Every 5-10 years sludge accumulated at the bottom of the lagoon should be removed

3.5 Technology Ranking

Based on information provided by EC and PWGSC, the following criteria were selected to evaluate how suitable each technology would be for use at Eureka:

- Treatment performance;
- Ease of operations;
- Risk and impact of process upset;
- Risk and impact of mechanical failure;
- Energy consumption;
- Capital cost; and,
- Sludge handling and disposal requirements.

The criteria are described below. Each technology was given a score of 1, 2 or 3 for each ranking criteria. A score of 3 indicates a technology that provides relatively good performance for the criteria, and a score of 1 indicates that the technology provides relatively poor performance on the criteria.

3.5.1 Treatment Performance

The Site's current NWB licence requires treatment to meet the criteria in Table 4. These effluent criteria are consistent with the typical effluent criteria provided in the "Guidelines for the Discharge of Treated Municipal Wastewater in the Northwest Territories", 1992. The NWB refers to this guideline when establishing effluent criteria for wastewater treatment in Nunavut.

Table 4: Current NWB Effluent Criteria for Eureka

Parameter	MAC – Maximum Average Concentration (mg/L)
Biochemical Oxygen Demand (BOD_5)	100
Total Suspended Solids (TSS)	120

The waste discharged shall have a pH between 6 and 9, and no visible sheen of oil and grease.

Based on discussion with PWGSC and EC, we understand that it is desired to select a technology that can meet secondary effluent criteria (i.e. BOD<30 mg/L, TSS<30 mg/L). The technologies were therefore scored as follows:

Table 5: Treatment Performance Scores

Score	Technologies	Rationale
1	New lagoon	Could meet NWB standards (100 mg/L BOD, 120 mg/L TSS), but likely could not meet secondary treatment standards reliably (30 mg/L BOD, 30 mg/L TSS)
2	Conventional AS Media-based trickling filter AS with integrated clarifier RBC	Could meet secondary treatment standards reliably (30 mg/L BOD, 30 mg/L TSS)
3	SBR Fixed film AS	Could meet secondary treatment standards (BOD<30 mg/L, TSS<30 mg/L); could provide tertiary treatment for one or more parameters

Any of the technologies could be combined with additional process steps to improve effluent quality (such as adding an Actiflo® or membrane filter for additional solids separation and phosphorus removal, introducing a recycle line or for nitrogen removal, or adding aeration to the lagoon). For the current rankings, we have considered the technologies without additional process steps beyond those required to meet secondary treatment standards.

3.5.2 Ease of Operations

Ease of operations considers both the time and expertise required from the operator for on-going maintenance and operations. This criteria considers only standard operations and maintenance requirements, and does not consider unexpected mechanical or process failure, which are considered in "risk and impact of mechanical failure" and "risk and impact of process failure", below.

The technologies were ranked as follows:

Table 6: Ease of Operations Scores

Score	Technologies	Rationale
1	SBR	Significant time commitment required from operator; skilled operator required • Frequent process adjustments may be required to cope with fluctuations in flows; system relies on relatively complex computerized process control to maintain treatment levels • Daily operator checks would be required with increased involvement if regular adjustments are required
2	RBC Conventional AS New lagoon	Moderate time required from operator; skilled operator may be required • RBC will require periodic process adjustments to cope with fluctuations in flows; operator will have to be comfortable with the computerized process control system to adjust properly • AS with separate clarifier would have simple control system requiring more frequent adjustment than higher ranking options • Lagoon would require longer operator attention at discharge period in summer; minimal maintenance at other times
3	Fixed film trickling filter AS with integrated clarifier Submerged fixed film bioreactor	Low maintenance and operation requirements; processes designed to operate for long periods without operator intervention; requires only simple maintenance tasks such as air filter replacement and monthly checks

3.5.3 Risk and Impact of Process Upset

Small scale wastewater treatment facilities are generally subject to larger fluctuations in influent flow quality and quantity than are larger wastewater treatment facilities. This is particularly true at Eureka, as the station population can vary between 8 and 100 people depending on the time of year. Therefore, a treatment technology should be selected that can adapt to broad changes in influent quality or quantity without this resulting in process upset or a significant drop in effluent quality.

In all cases except for the lagoon, discharge of toxic chemicals in the sewage system will have a detrimental impact on its performance. The likelihood of such discharge to occur should be reviewed by the personnel at the site. Some changes to current practices might be required, especially regarding the type of cleaning agents currently used at the site. Materials that could contribute parameters that are elevated in the lagoon sludge should also be reviewed (e.g. arsenic and copper).

Table 7: Risk and Impact of Process Upset Scores

Score	Technologies	Rationale
1	SBR Media-based trickling filter	Moderate risk of process upset; operator could likely not resolve major process upset alone (would require parts and/or technical support from outside Eureka) • SBR process failure could require skilled operator to visit site to reset process control system; loss of sludge activity could result in extended period with reduced effluent quality • Media in the media-based trickling filter can become fouled; new media may have to be shipped from manufacturer.
2	RBC AS with integrated clarifier Submerged fixed film bioreactor Conventional AS	Low risk of process upset; upset could likely be resolved by onsite operator • Fixed film on RBC media and in partially submerged fixed film bioreactor resistant to kill off with changes in flow rate • AS systems are fairly robust; process tanks could be flushed if required (for example, in case of toxic material entering treatment system)
3	New lagoon	Very low risk of process upset • Very long holding time (>1 year) will buffer changes in flows and influent quality; process upset unlikely

3.5.4 Risk and Impact of Mechanical Failure

The risk and impact of mechanical failure considers both the likelihood of failure of mechanical components (such as pumps and blowers) and the potential impact (reduced system performance, downtime during repair, need for staff or equipment from off site to complete repair).

Table 8: Risk and Impact of Mechanical Failure Scores

Score	Technologies	Rationale
1	RBC SBR	Moderate risk of mechanical failure; operator could not resolve major failures alone; could result in long-term disruption to treatment system for repairs • Shaft failure of RBC would require new unit to be shipped to Eureka; failure could impact operations until following summer • SBR has control panel that controls pumps, air blower, valves and timers for each of these equipment; mechanical failure could require reprogramming the control panel which may require technical support from outside of Eureka
2	Media-based trickling filter AS with integrated clarifier Submerged fixed film bioreactor Conventional AS	Moderate risk of mechanical failure; upset could likely be resolved by onsite operator with replacement parts that are be kept onsite (ex. blowers, pumps, fans); minimal disruption to treatment system for repair • Media-based trickling filter uses pumps and air fan • AS with integrated clarifier uses pumps and a blower • Submerged fixed film bioreactor uses pumps and blower • AS with separate clarifier uses pumps, blower and diffusers
3	New lagoon	Low risk of mechanical failure; upset could likely be resolved by onsite operator with replacement parts that could be kept onsite; little or no disruption to treatment system for repair • New lagoon would require transfer pump only; pump used for short period in summer only

3.5.5 Energy Consumption

The energy (electrical and direct heating energy) consumption includes the following:

- electrical demands of mechanical equipment (pumps, blowers, heaters, etc.); and,
- heating the treatment building (if required) and treatment units to operational temperature.

Of these factors, the energy required heat the treatment building has the largest impact on the energy consumption.

Table 9: Energy Consumption Scores

Score	Technologies	Rationale
1	RBC AS with integrated clarifier Submerged fixed film bioreactor Conventional AS	Significant mechanical equipment (blowers, pumps, motor to rotate the RBC); the units are also relatively larger and therefore require larger buildings and more energy for heating • RBC has motor for shaft rotation; relatively large horse power (hp) motor with constant demand • AS with integrated clarifier has pumps and a blower; relatively large hp blower with constant demand • Submerged fixed film bioreactor has pumps and a blower; relatively large hp blower with constant demand • AS with separate clarifier uses pumps and a blower; relatively large hp blower with constant demand
2	SBR Media-based trickling filter	Relatively smaller units with less building heating requirements or significantly less power required for mechanical components • Although SBR has a blower, the blower operates intermittently; relatively large hp blower with intermittent demand • Media-based filter has a fan rather than a blower to supply air to the system; low hp power with constant demand
3	New lagoon	No building is required so no energy is required for heating requirements; minimal energy consumption • Lagoon requires a heat-traced forcemain to lagoon and pumps to transfer liquid between cells and discharge during warm season

3.5.6 Capital Cost

The capital cost includes the unit price of each technology, with approximate shipping, construction and design cost. The construction costs for the new lagoon includes blasting, drilling, and transportation of construction equipment (drills, excavator, dozer, etc.). The other technologies are available prefabricated from suppliers; these technologies can generally be delivered to site in shipping containers.

Table 10: Capital Cost Scores

Score	Technologies	Rationale
1	New lagoon	Significantly higher initial capital cost than other options • New lagoon would need excavation into the permafrost layer (blasting); high costs to transport equipment (drills, excavator, dozer, etc.)
2	RBC AS with integrated clarifier Submerged fixed film bioreactor Conventional AS	Higher capital cost than the SBR and the media-based trickling filter
3	SBR Media-based trickling filter	Lowest initial capital cost

3.5.7 Sludge Handling and Disposal Requirements

This criterion considers the frequency of sludge handling and the sludge storage requirements.

Table 11: Sludge Handling and Disposal Requirement Scores

Score	Technologies	Rationale
1	RBC SBR Conventional AS	All require daily or weekly handling of sludge to control solids concentration in reactor; handling cannot be deferred until summer; sludge must be handled on a year round basis; highest overall volume of sludge produced
2	Media-based trickling filter AS with integrated clarifier Submerged fixed film bioreactor	All require sludge handling every 1-3 years; handling can be deferred until summer; moderate sludge production
3	New lagoon	Would require sludge handling every 10 to 20 years; lowest sludge production

3.6 Criteria Weighting

Based on our recommendations and input from PWGSC and EC, the ranking criteria were assigned weightings as per Table 12 (note that a higher weighting indicates higher relative importance of this criteria).

Table 12: Criteria Weighting

Criteria	Weighting
Treatment performance	2
Ease of operations	4
Risk and impact of process upset	3
Risk and impact of mechanical failure	4
Energy consumption	4
Capital Cost	1
Sludge handling and disposal requirements	1

3.7 Summary of Ranking Results and Short Listed Technologies

The technology scores for each of the criteria are tabulated below. The scores for each technology were multiplied by the weighting for that criterion and added together to determine the overall technology score.

Table 13: Summary of Technology Rankings

Treatment Technology	Treatment Performance	Ease of Operations	Risk and Impact of Process Upset	Risk and Impact of Mechanical Failure	Energy Consumption	Capital Cost	Sludge handling and disposal	Total
	Criteria							
	Weighting							
	2	**4**	**3**	**4**	**4**	**1**	**1**	
Sequencing Batch Reactor (SBR)	3	1	1	1	2	3	1	29
Rotating Biological Contactor (RBC)	2	2	2	1	1	2	1	29
Conventional Activated Sludge with Separate Clarifier	2	2	2	2	1	2	1	33
Integrated Activated Sludge and Clarifier (such as Whitewater ®)	2	3	2	2	1	2	2	38
Media-based trickling filter (such as Waterloo Biofilter®)	2	3	1	2	2	3	2	**40**
Submerged fixed film bioreactor (such as FAST®)	3	3	2	2	1	2	2	**40**
New Lagoon (2 cell facultative)	1	2	3	3	3	1	3	**47**

Based on the technology rankings, the shorted listed technologies are the three technologies with the highest overall score:

- Media-based trickling filter
- Submerged fixed film bioreactor
- New 2-cell facultative lagoon

4.0 CONCEPTUAL SITE AND INSTALLATION PLANS

Conceptual site plans and conceptual installation plans have been prepared for each short listed technology to assist with EC and PWGSC planning. Both the site plans and the installation plans were used in developing the detailed capital and lifecycle cost estimates for each technology.

4.1 Submerged Fixed Film Bioreactor and Media-based Trickling Filter

The site plan for the submerged fixed film bioreactor and media-based trickling filter would be very similar. Both systems would be installed in a treatment building with estimated dimensions of approximately 18x18 metres. A new or partly reused forcemain (insulated and heat traced) would be needed from the treatment building to outlet either to the existing lagoon (maintained for effluent storage), or directly to the fjord (see Section 7.1 for a discussion of effluent disposal options). Figure 3 shows the conceptual site plan for these two options.

The installation plans for these two options would also be very similar. With an aggressive schedule, either system could likely be installed and commissioned in a single summer, with the equipment being shipped offsite the following summer, as follows:

1) In the fall of year 1, all materials, including the treatment unit, the prefab treatment building and the heavy equipment required to install the treatment building would be delivered to site.
2) In the summer of year 2, the treatment building would be erected with the treatment unit inside. The outlet piping would be installed, either to existing lagoon (if the lagoon is to be maintained for seasonal discharge) or to a year round discharge above the fjord. The existing forcemains from the new and former main complex would be directed to new treatment unit, and the treatment unit would be commissioned.
3) The heavy equipment would be shipped offsite in the fall of year 2.

4.2 New Lagoon

Based on the limited site information available, we have provided two options for where a new lagoon could be located (see Figures 4 and 5). Option 1 is closer to both the site buildings and the fjord than is option 2. The capital and operating costs would therefore be less for option 1 than for option 2. However, option 1 may not be practical given the existing hydrogen storage building and power line infrastructure nearby. The lagoon location would therefore have to be refined at the design stage by the design engineers, PWGSC and EC, with the input of an experienced drilling and blasting company. With either option, a new lagoon would require an extended forcemain to connect to the new lagoon structure. The existing lagoon is located at a lower elevation than the pumping station such that the forcemain empties by gravity into the lagoon when pumping stops, eliminating the possibility of effluent freezing within the forcemain. The new lagoon location options are both at a higher elevation than the pumphouse. Therefore, it must be confirmed during detailed design that the pumping station has sufficient volume to hold the drainback volume from the forcemain. The storage volume of the pumping station may have to be increased.

Installation of a new lagoon would require considerable equipment for drilling, blasting and earthworks. The equipment could be delivered to site by sea or by air (Hercules aircraft). Because sea shipment is possible only one time per year, equipment would have to be kept on standby for the remainder of the year following use.

However, sea shipment would still be considerably less expensive, even when equipment standby rates are taken into account. We have developed a conceptual installation plan with lagoon construction taking place over two summers, as follows:

1) In the fall of year 1, blasting equipment (drill rig, blasting mats) and the heavy earth moving equipment (excavator, dump truck, etc.) would be delivered to site.
2) In the spring of year 2, the first lagoon cell would be excavated (blasting is simpler when full depth of ground is still frozen).
3) In the summer of year 2, the excavated material would be removed from the first lagoon cell and the cell shaped.
4) In the spring of year 3, the second lagoon cell would be excavated.
5) In the summer of year 3, the excavated material would be removed from the second lagoon cell and the cell shaped. The liner would be installed in both cells.
6) The lagoon would be commissioned in the fall of year 3 with a new forcemain connecting it to the existing.
7) All heavy equipment could be shipped offsite with the year 3 restock.

5.0 DETAILED COST ESTIMATES

5.1 Methodology and Assumptions

Life cycle cost estimates were prepared for the short listed options based on information obtained from Environment Canada and Public Works and Government Services Canada, manufacturers, suppliers and contractors and from experienced Golder Associates Ltd. personnel.

Key assumptions in the estimates include:

- The costs for the treatment building (if required) are based on a dome or framed style building constructed on a wood sill foundation on natural ground.
- Sufficient fuel storage and power generation capacity is available to meet new power requirements.
- Fuel costs and power generation efficiencies are based on data provided by EC for Eureka.
- Existing infrastructure (pumping stations, piping) will be suitable for reuse.
- The cost for effluent disposal and monitoring infrastructure is not included, as this cost depends on the disposal option selected.
- The cost of sludge handling infrastructure is not included.
- Labour for routine maintenance to be carried out by onsite staff (no additional labour costs carried)
- Shipping costs are based on commercial shipping rates to Nanisivik from Valleyfield, Quebec. Shipping from Nanisivik to Eureka with the Coast Guard icebreaker is not included.

The estimated capital costs include design, materials, labour and equipment time, and transportation costs to Eureka. These costs are presented separately in Section 5.2 for each option. Note that these costs do not include minor components and details that are beyond the scope of this stage. For this reason, a contingency for these items should be added to all costs (15 to 25%).

A lifecycle cost estimate has also been prepared that factors in ongoing power consumption and equipment replacement costs based on their life expectancies. These components are added to the capital cost tables to present the anticipated costs of construction and operation over 20 and 40 years. The net present value (NPV) of each option after 20 and 40 years has been estimated using an inflation rate of 2% and an interest rate of 4%. These costs are presented in Section 5.3. The lifecycle costs are sensitive to changes in the heating requirements and power consumption. The costs may vary considerably with changes in fuel cost or building design.

5.2 Initial Cost

5.2.1 Submerged Fixed Film Bioreactor

The initial system cost for a submerged fixed film bioreactor is estimated in Table 14.

Table 14: Initial Capital Cost for Submerged Fixed Film Bioreactor

Item	Materials Cost	Transportation Cost	Installation Cost	Total Initial System Cost
FAST system	$390,537	$75,200	$45,600	$511,337
Equalization basin	$5,000	$6,300	$2,500	$13,800
Grease interceptor	$14,000	$410	$0	$14,410
Building (Dome) with insulation	$107,500	$75,200	$111,750	$294,450
Foundation and flooring	$114,750	$68,900	$45,000	$228,650
Piping	$31,500	$6,300	$25,000	$62,800
Electrical and plumbing connections	$5,000	$50,000	$20,000	$75,000
Design fee and geotechnical inspection	$70,000	$100,000	$0	$170,000
Construction management cost (15%)	205,567	50,000	$0	$205,567
Contingency (35%)	551,605	$0	$0	$551,605
			TOTAL	**$2,127,619**

5.2.2 Media-based Trickling Filter

The initial system cost for the media-based trickling filter is estimated in Table 15.

Table 15: Initial Capital Cost for Media-Based Trickling Filter

Item	Materials Cost	Transportation Cost	Installation Cost	Total Initial System Cost
Waterloo Biofilter system	$250,000	$75,200	$45,600	$370,800
Grease interceptor	$14,000	$410	$0	$14,410
Equalization basin	$5,000	$6,300	$2,500	$13,800
Building (Dome) with insulation	$88,000	$75,200	$111,750	$274,950
Foundation	$107,500	$68,900	$45,000	$221,400
Piping	$31,500	$6,300	$25,000	$62,800
Electrical and plumbing connections	$5,000	$50,000	$20,000	$75,000
Design fee and geotechnical inspection	$70,000	$100,000	$0	$170,000
Construction management cost (15%)	180,474	50,000	$0	$180,474
Contingency (35%)	484,272	$0	$0	$484,272
			TOTAL	**$1,867,906**

5.2.3 New Lagoon

Two locations were considered for the new lagoon. Option 1 is located closer to the fjord. Option 2 is across the road, further from the fjord. For option 2, we have included a contingency for additional piping if it is desired to locate the lagoon even further from the main complex.

The initial system cost for option 1 is estimated in Table 16.

Table 16: Initial System Cost for New Lagoon Option 1

Item	Materials Cost	Transportation Cost	Installation Cost	Total Initial System Cost
2-cell lagoon	$0	$311,600	$805,000	$1,116,600
Liner	$55,215	$62,600	$34,000	$151,815
2 pumps	$5,000	$410	$0	$5,410
Piping	$90,000	$6,300	$25,000	$121,300
Extra piping cost for further location	$90,000	$6,300	$25,000	$121,300
Electrical and plumbing connections	$5,000	$50,000	$20,000	$75,000
Design fee and geotechnical inspection	$100,000	$100,000	$0	$200,000
Construction management cost (15%)	268,714	50,000	$0	$268,714
Contingency (35%)	721,049	$0	$0	$721,049
			TOTAL	**$2,781,187**

The initial system cost for option 2 is estimated in Table 17.

Table 17: Initial System Cost for New Lagoon Option 2

Equipment	Materials Cost	Transportation Cost	Installation Cost	Total Initial System Cost
2 cell lagoon	$0	$311,600	$805,000	$1,116,600
Liner	$55,215	$62,600	$34,000	$151,815
2 pumps	$5,000	$410	$0	$5,410
Piping	$190,000	$12,600	$40,000	$242,600
Extra piping cost for further location	$190,000	$12,600	$40,000	$242,600
Electrical and plumbing connections	$5,000	$50,000	$20,000	$75,000
Design fee and geotechnical inspection	$100,000	$100,000	$0	$200,000
Construction management cost (15%)	305,104	50,000	$0	$305,104
Contingency (35%)	818,695	$0	$0	$818,695
			TOTAL	**$3,157,824**

5.3 Lifecycle Cost Estimates

Based on the method described in Section 5.1, lifecycle cost estimates were prepared for each of the short listed technologies. The detailed estimates are included in Appendix C, and a summary of the NPV after 20 and 40 years is provided below. The 20 and 40 year costs include replacement costs for components based on the life expectancy (e.g. pumps are replaced every 10 years).

Table 18: Lifecycle Cost Estimates

Treatment System	NPV after 20 Years	NPV after 40 Years
Submerged fixed film bioreactor	$2,704,399	$3,105,792
Media-based trickling filter	$2,169,894	$2,388,418
New lagoon (Option 1)	$2,968,549	$3,077,430
New lagoon (Option 2)	$3,349,187	$3,482,438

5.4 Cost Estimates for Other Technologies

For comparative purposes, we have provided rough initial capital costs and 20 and 40 year lifecycle costs for the technologies that did not make the short list (Table 19). We have included the more detailed estimates for short listed technologies for comparison.

Table 19: Cost Estimates for Other Technologies

Treatment System	Initial Capital Cost	NPV after 20 Years	NPV after 40 Years
SBR	$1.84 mil	$2.05 mil	$2.24 mil
Media-based Trickling Filter*	$1.87 mil	$2.17 mil	$2.39 mil
Integrated activated sludge and clarifier	$2.08 mil	$2.63 mil	$3.08 mil
Conventional activated sludge with separate clarifier	$2.02 mil	$2.56 mil	$2.99 mil
RBC	$2.13 mil	$2.40 mil	$2.90 mil
Submerged Fixed Film Bioreactor*	$2.13 mil	$2.70 mil	$3.11 mil
Lagoon Option 1*	$2.78 mil	$2.97 mil	$3.08 mil
Lagoon Option 2*	$3.16 mil	$3.35 mil	$3.48 mil

*Short listed technology

6.0 SLUDGE HANDLING RECOMMENDATIONS

The sludge handing requirements will depend on which treatment option is selected. The short listed technologies require minimal sludge handling as compared with some other treatment technologies (some of which would require daily or weekly sludge handling). Both the fixed film activated sludge system and the media-based trickling filter are designed to retain sludge for an extended period of time (1-3 years) before being pumped out. With a lagoon, sludge will gradually accumulate on the bottom, and must be periodically pumped out (generally every 10 to 20 years). With all the short listed technologies, the long sludge retention time will reduce the sludge considerably, as the sludge will be partially digested within the treatment system.

The volumes of sludge produced by the short listed technologies will be quite small. The pre-treatment settling tanks of the submerged fixed film bioreactor and the trickling filter would be pumped out every 1-3 years. The sludge volume would depend on the final design of either system, but a volume of approximately 30 m^3 could be expected every 1-3 years. The sludge volume from a lagoon is difficult to predict as the volume depends not only on the volume and characteristics of the waste treated but on sludge removal system (i.e. how much water must be removed with the sludge). However, the sludge volumes produced should be lower than for either the submerged fixed film bioreactor or the trickling filter, as the lagoon has a considerably longer sludge holding time.

Once removed from the treatment system, the sludge will have to be dewatered. There are numerous options available for dewatering at larger facilities with full time operators and relatively constant sludge production (such as centrifugation, filter presses, and heat drying). For a site such as Eureka with intermittent sludge removal, passive dewatering is recommended. We have considered both Geotubes and a simplified drying bed.

Geotubes provide both dewatering and containment through passive filtration of conditioned sludge. Considerably more infrastructure would be required for implementation (as compared with a drying bed), as the sludge must be pre-conditioned before dewatering, and the filtrate must be returned to the treatment system.

Drying beds are most suitable when sufficient land area is available, and when the drying bed can be sufficiently isolated so as to avoid issues with initial nuisance odours. Depending on the climate and site requirements, drying beds can range from very simple to moderately complex. In most areas, the precipitation is greater than the evaporation, so drying beds must either be protected from precipitation, or liquid must be collected at the bottom of the bed and returned to the treatment system. Based on precipitation data from Environment Canada and evaporation data from the Department of Fisheries and the Environment (see Water Balance in Section 2.1), Eureka is located in a polar desert area, and evaporation exceeds precipitation. Therefore, a very simple evaporation-based design can be used for drying beds.

We recommend that a simple 2-cell drying bed be constructed at Eureka. The cells can be constructed by excavating a shallow bed area within the active layer using the earth moving equipment available on site. No additional infrastructure would be required. Each cell should be sized to hold a minimum of 10 years of sludge. The sludge can likely be transported to the drying bed using the truck currently used to transport sewage on site, although the volume of this truck should be confirmed to ensure it is large enough to be practical. The two cells can be used on an alternating basis to allow sufficient time for dewatering and sludge stabilization. The freeze thaw cycles would assist in stabilization of the sludge. The dried sludge could be left in place or removed to the site's landfill.

7.0 EFFLUENT DISPOSAL AND MONITORING RECOMMENDATIONS

7.1 Effluent Disposal Options

Regardless of what treatment option is selected, either year round or seasonal discharge can be considered. Seasonal discharge would require storage of at least 10 months of treated effluent (minimum 2020 m^3). With year round discharge, significant effluent storage is not required; however, effluent discharge logistics (including effluent monitoring) would be substantially more complex. Three options have been considered: year round discharge to fjord using a submerged outfall, year round discharge to the fjord with an elevated outfall, and effluent storage for seasonal discharge.

Year round discharge to fjord using a submerged outfall. The *Guidelines for the Discharge of Treated Municipal Wastewater in the Northwest Territories* includes basic requirements for design of treated effluent outfalls. A minimum horizontal distance to the closest point of discharge from mean low water mark is provided based on the flow rate and the depth of discharge below mean low water or underside of ice. A submerged outfall may also require approval under the federal *Fisheries Act*. The practical requirements for a submerged outlet cannot be established without a review of bathymetric information for the fjord near the site. The potential for ice scour would also have to be considered, as this could cause significant damage to the effluent outfall piping.

Year round discharge to fjord using an elevated outfall. Sewage from the site is currently being discharged to the lagoon on a year round basis from an outfall approximately 2.5 metres above the lagoon surface. In the winter, the effluent freezes below the outfall, but the vertical drop is large enough that the frozen effluent does not interfere with the outfall. A similar arrangement could be used to allow year round discharge to the fjord using an elevated outfall. The available information from EC indicates that there is a vertical drop of approximately 3 metres between the ground and fjord water level, although the height varies depending on the location along the shore. An effluent disposal pipe could therefore be located high enough above the fjord water at the shoreline so as to avoid complications associated with ice scour and frozen effluent below the outfall.

Effluent storage and seasonal discharge. If the existing sewage lagoon could be converted to an effluent storage lagoon, seasonal discharge would be the most economical option for effluent disposal. If a new effluent storage lagoon were required, the cost for seasonal discharge would likely be prohibitive, as a new lagoon would likely have to be constructed by blasting into the permafrost.

EC's licence from the NWB indicates that no land-based activities should be conducted within thirty metres of the ordinary high water mark of any water body unless otherwise approved by the NWB. Therefore, NWB approval would be required for continued use of the lagoon for effluent storage. The environmental risks associated with use of the lagoon for effluent storage would be minimal, as the effluent would already be treated to the level required for discharge into the fjord. In order to convert the lagoon for effluent storage, and any accumulated sludge would have to be removed and addressed separately. Sampling of both the sludge and the material below the lagoon would be recommended to assess the potential impact of existing subsurface contamination on the future effluent quality, although the impacts are likely negligible.

Year round discharge using above ground piping is considered a more feasible option than a submerged outfall.

7.2 Effluent Monitoring

Effluent quality monitoring can be complex in remote regions due to sample shipping delays and time constraints for the sample to be received by a laboratory to provide valid results.

Current licence requires EC to monitor for the parameters in Table 20.

Table 20: Parameters Requiring Monitoring Under Current NWB Licence

Parameter	Compliance parameter?
Biochemical oxygen demand (BOD_5)	YES (less than 100 mg/L)
Total suspended solids (TSS)	YES (less than 120 mg/L)
pH	YES (6-9)
Oil and grease (visual)	YES (no visible oil and grease)
Conductivity	NO
Major cations (calcium, magnesium, potassium, sodium)	NO
Nutrients (ammonia-nitrogen, nitrate/nitrite, phosphorus)	NO
Sulphate	NO
Oil and grease (laboratory)	NO
Total phenols	NO

Most of the above parameters can be stored for considerable time (with and without preservation) to permit submission to the laboratory. For the compliance parameters pH and BOD, the accuracy of the results can be affected by storage. TSS can also be impacted by excessive storage times to some extent. On-site testing equipment has improved considerably in the last decade and could be considered at this and other remote locations. The ease of use can vary but most are designed to be largely automated.

Electronic self-cleaning TSS sensors are available from manufacturers such as MJK. The sensor can electronically monitor TSS from 0 to 200 mg/L using a sensor designed for final effluent monitoring. The sensors are placed directly in the wastewater flow (turbulent flow is acceptable) and solids are measured using optical lens that require only periodic inspection and infrequent clean water calibration. Operating temperatures are from 0 to 60 C and storage temperatures are from -20 to 60 C. The instrument could be controlled remotely (to adjust operating range) or transmit data remotely via a USB cable to a computer or can an analog signal to a process controller. Costs for a TSS analyzer are about $12,000.

There are test units available that can measure BOD at remote locations, however they are expensive ($60,000-$80,000) and require considerable maintenance and training. Culture seeds are required to be kept available at all time which requires care and monitoring.

Chemical Oxygen Demand (COD) can be used as an indicator of BOD based on textbook values and it may be possible to develop a correlation of COD to BOD in the effluent specific to Eureka. A study may be required after plant commissioning to demonstrate the relationship between COD and BOD. Approval would be required for this unique approach. Instruments are available for on-line monitoring/approximation of COD. Datalink Instruments manufacturers an analyzer that approximates COD with UV light. The amount of light absorbed by a sample is correlated to the COD. A peristaltic pump collects a water sample via plastic tubing to the instrument where the measurements are taken. Coarse filtration of the sample is not required. The unit would require periodic cleaning and maintenance. The instrument could be controlled remotely and transmit data remotely via an RS232 connection to a computer or an analog signal to a process control unit. Costs for a COD analyzer are from about $20,000 to $30,000.

8.0 DECOMMISSIONING RECOMMENDATIONS

A conceptual plan is provided below for decommissioning of existing wastewater infrastructure, including the following items:

- Sewage pumping station (next to main complex)
- Piping to the sewage lagoon
- Sewage lagoon

Based on site photographs, the sewage pumping station appears to have an underground pumping chamber. This tank should be backfilled for safety. The associated building should be dismantled and taken to the site's landfill. The building should be inspected before being dismantled to identify if building materials are present that warrant additional attention during disposal (ex. asbestos, lead paint, mercury from light ballasts).

Any aboveground piping can be dismantled and removed to the site's landfill. Below ground piping can be left in place if desired or disposed of at the site's landfill. If left in place, the piping should be sealed to prevent the decommissioned piping from acting as a conduit for contaminant transport.

A National Research Council (NRC) investigation in 2006/2007 included sampling of the liquid and sediment in the sewage lagoon. The results were presented in the NRC report "Characterization of Contaminated Sites at CFS-Alert and CFS-Eureka, Nunavut" (March 31, 2007). These results will provide an indication of the likely characteristics of the lagoon sludge. Maintaining the sludge as a soil or soil amendment is the most practical option if the quality is suitable. The above investigation sampled at various depths in the sludge and slight exceedances of the soil quality guidelines were measured for arsenic and copper in some samples. After the sludge is removed and mixed, the bulk concentration may meet both criteria. Mixing with soils on site may be an option for consideration.

Once the final effluent has been discharged from the sewage lagoon, the remaining sludge and adjacent overburden material should be sampled and tested to provide current information. If no contamination issues are identified based on the bulk sludge characterization, the sludge can be left in place and the lagoon backfilled. If the sewage lagoon is to be maintained as an effluent storage lagoon, the sludge can be removed to sludge drying beds for dewatering. If contamination issues are identified, additional investigation, risk assessment, treatment or disposal options may be required.

9.0 SUMMARY OF RECOMMENDATIONS

A summary of the recommendations is provided below.

Treatment Technologies. Based on a ranking of treatment technology options, three treatment technologies were short listed for further consideration:

- Media-based trickling filter;
- Submerged fixed film bioreactor; and,
- New 2-cell facultative lagoon.

Of these options, the media-based tricking filter has the lowest initial system cost and the lowest lifecycle costs after 20 and 40 years. However, another of the short listed technologies may be selected based on the other evaluation criteria (treatment performance, ease of operations, risk and impact of process upset, risk and impact of mechanical failure, or sludge handling and disposal requirements).

Sludge Handling. Sludge handling requirements will depend on which treatment option is selected. A very simple drying bed is recommended to provide passive dewatering and sludge stabilization. The drying bed can be constructed in the active layer using equipment available on site.

Effluent Disposal. Three effluent disposal options were considered, including year round discharge to the fjord to a submerged outfall, year round discharge to the fjord using an elevated outfall, or effluent storage and seasonal discharge. If the existing sewage lagoon can be converted to an effluent storage lagoon, seasonal discharge would be the most economical option.

Effluent Monitoring. Effluent monitoring recommendations are provided based on the site's existing monitoring requirements. On-site testing should be considered for parameters that have holding time restrictions.

REFERENCES

Metcalf and Eddy, *Wastewater Engineering Treatment and Reuse* Fourth Edition, McGraw Hill, 2003.

Department of Fisheries and the Environment, Atmospheric Environment Service, Hydrologic Atlas of Canada, 1975.

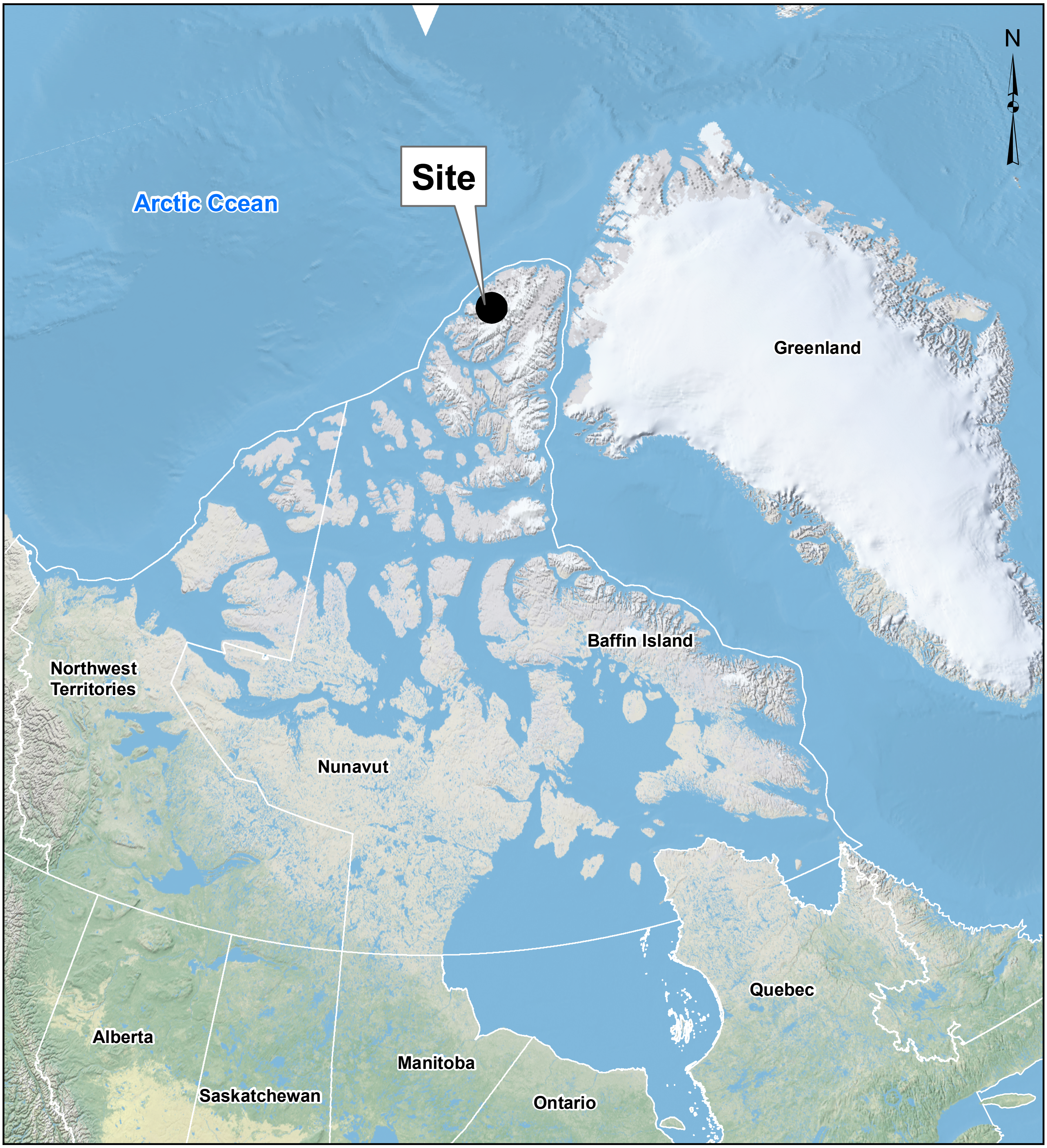
Report Signature Page

GOLDER ASSOCIATES LTD.

Elizabeth Love, B.E.Sc.
Environmental Consultant

Dennis Martin, M.Sc.(Eng.), P.Eng.
Associate, Senior Environmental Engineer and Hydrogeologist

EML/DGM/cm
n:\active\2009\1125 - environmental & civil engineering\09-1125-0005 pwgsc eureka wastewater\report\09-1125-0005 final reportrev by dgm april7-2009.doc



750 0 750

1:22,000,000 Kilometers

NOTE:
This figure is to be read in conjunction with the accompanying Golder Associates Ltd. report No. 09-1125-0005

PROJECT
PWGSC Wastewater Treatment Options
Eureka, Nunavut

TITLE
Key Plan

Golder Associates
Calgary, Alberta

PROJECT No. 09-1125-0005			SCALE AS SHOWN	REV. 0
DESIGN	LL	12 Mar. 2009	**FIGURE: 1**	
GIS	AB	12 Mar. 2009		
CHECK	EML	12 Mar. 2009		
REVIEW	DGM	12 Mar. 2009		

N:\Active\2009\1125 - Environmental & Civil Engineering\09-1125-0005 PWGSC Eureka Wastewater\ACAD\Phase 3000\GIS\mxd\0911250005-3000-01.mxd

PLOT DATE: April 7, 2009
FILENAME: N:\Active\2009\1125 - Environmental & Civil Engineering\09-1125-0005 PWGSC Eureka Wastewater\ACAD\Phase 3000\0911250005-3000-02.dwg

NOTES:

1. THIS DRAWING / FIGURE IS TO BE READ IN CONJUNCTION WITH GOLDER ASSOCIATES LTD. REPORT No. 09-1125-0005.

REFERENCES:

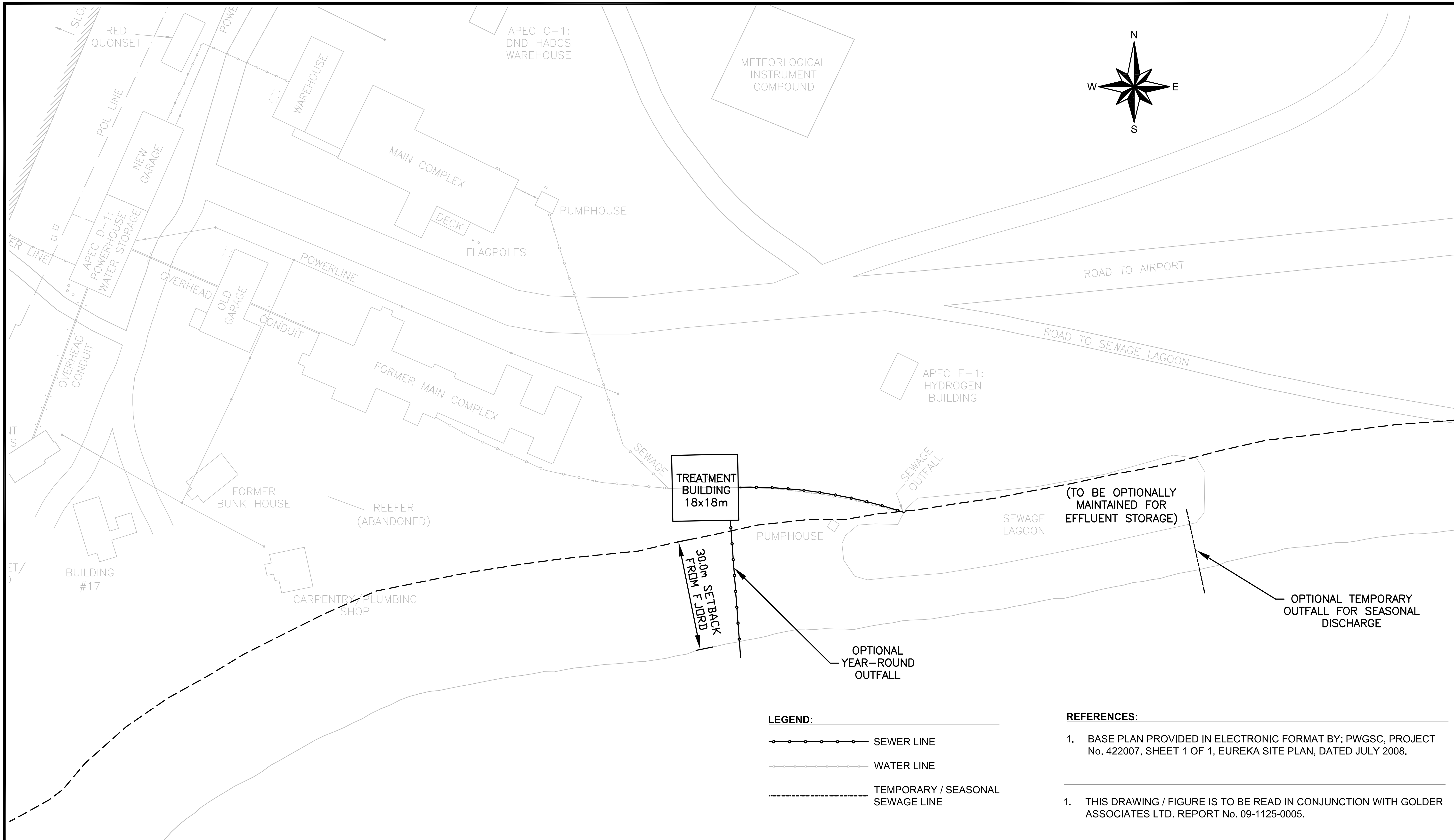
1. BASE PHOTO PROVIDED IN ELECTRONIC FORMAT BY: PWGSC PHOTO DATE AUG. 2007.

Golder Associates
Ottawa, Ontario, Canada

SCALE	N.T.S.	TITLE	**AIR PHOTO OF SITE**
DATE	12 Mar. 2009		
DESIGN			
CAD	M.L.F.		
CHECK	E.M.L.		PWGSC, WASTEWATER TREATMENT OPTIONS EUREKA, NUNAVUT
REVIEW	D.G.M.	FIGURE	2

FILE No. 0911250005-3000-02.dwg

PROJECT No. 09-1125-0005 REV. 0



LEGEND:

- SEWER LINE
- WATER LINE
- TEMPORARY / SEASONAL SEWAGE LINE

REFERENCES:

1. BASE PLAN PROVIDED IN ELECTRONIC FORMAT BY: PWGSC, PROJECT No. 422007, SHEET 1 OF 1, EUREKA SITE PLAN, DATED JULY 2008.

1. THIS DRAWING / FIGURE IS TO BE READ IN CONJUNCTION WITH GOLDER ASSOCIATES LTD. REPORT No. 09-1125-0005.

Golder Associates
Ottawa, Ontario, Canada

SCALE	1:1,000
DATE	12 Mar. 2009
DESIGN	E.M.L.
CAD	M.L.F.
CHECK	E.M.L.
REVIEW	D.G.M.

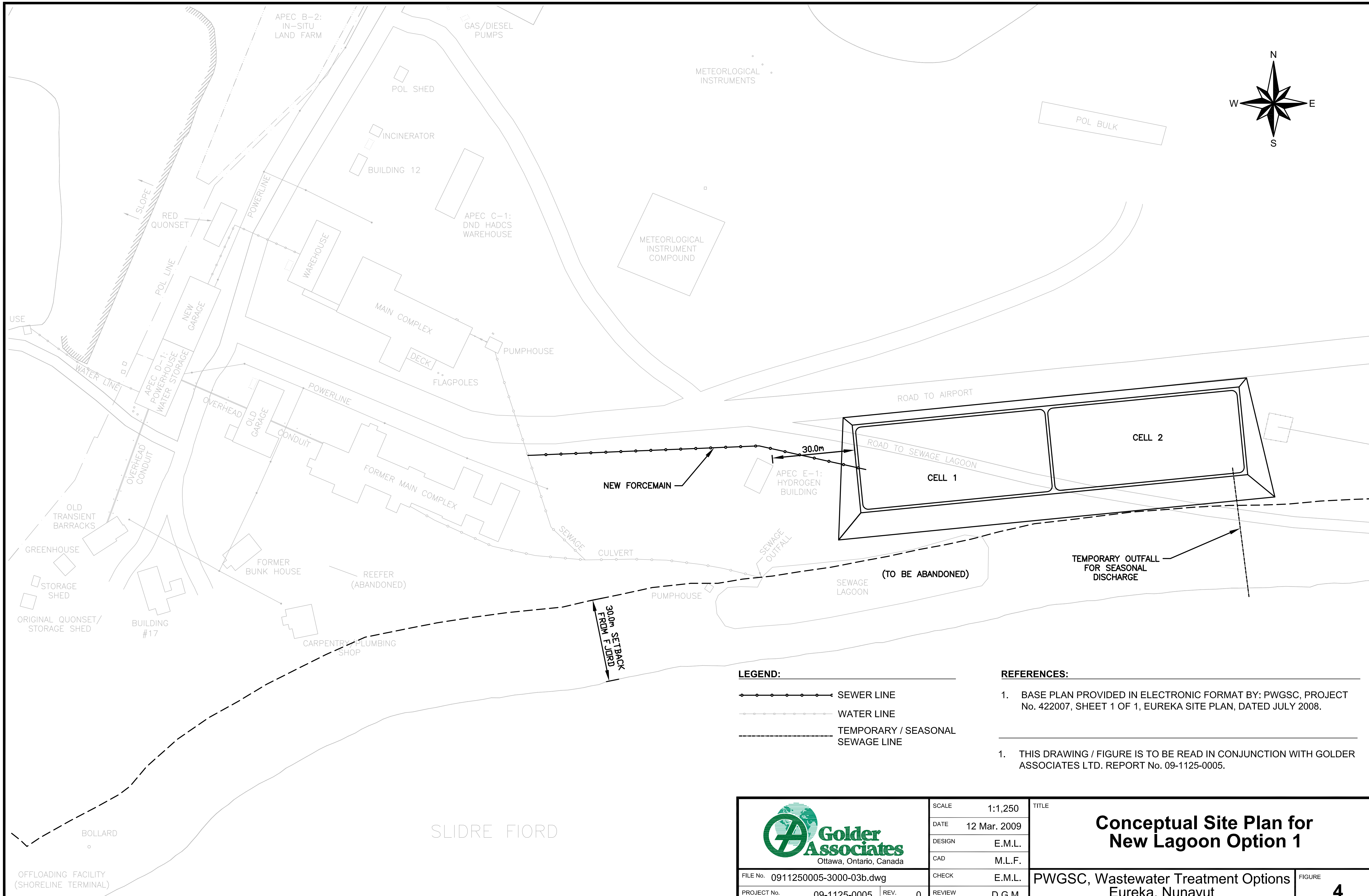
FILE No. 0911250005-3000-03b.dwg
PROJECT No. 09-1125-0005 REV. 0

TITLE
Conceptual Site Plan for Submerged Fixed Film Bioreactor and Media-Based Trickling Filter Options

PWGSC, Wastewater Treatment Options
Eureka, Nunavut

FIGURE 3

PLOT DATE: April 6, 2009
FILENAME: N:\Active\2009\1125 - Environmental & Civil Engineering\09-1125-0005 PWGSC Eureka Wastewater\ACAD\Phase 3000\0911250005-3000-03b.dwg



LEGEND:

SEWER LINE

WATER LINE

TEMPORARY / SEASONAL SEWAGE LINE

REFERENCES:

1. BASE PLAN PROVIDED IN ELECTRONIC FORMAT BY: PWGSC, PROJECT No. 422007, SHEET 1 OF 1, EUREKA SITE PLAN, DATED JULY 2008.

1. THIS DRAWING / FIGURE IS TO BE READ IN CONJUNCTION WITH GOLDER ASSOCIATES LTD. REPORT No. 09-1125-0005.

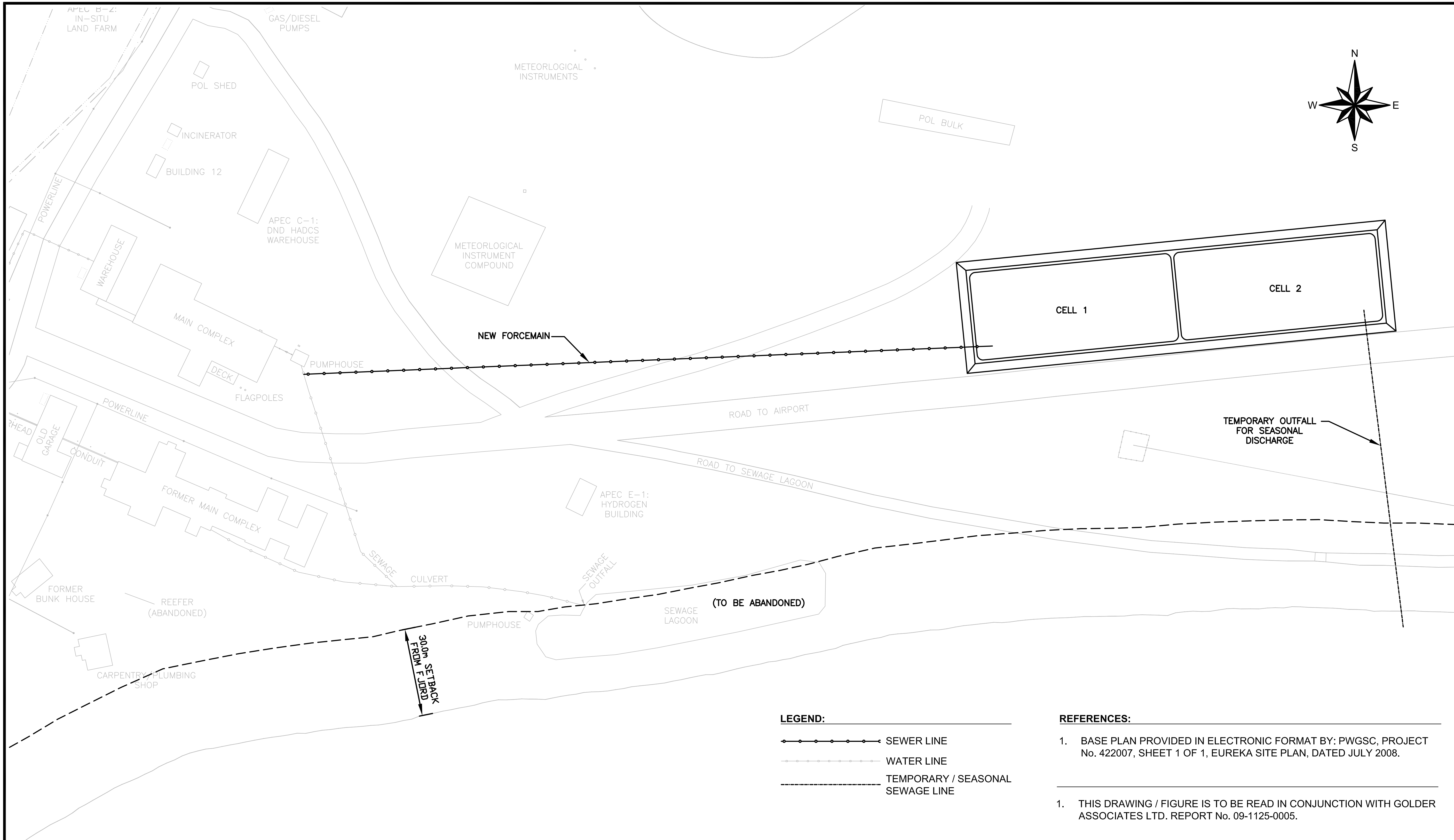
Golder Associates
Ottawa, Ontario, Canada

SCALE	1:1,250	TITLE	**Conceptual Site Plan for New Lagoon Option 1**
DATE	12 Mar. 2009		
DESIGN	E.M.L.		
CAD	M.L.F.		
FILE No. 0911250005-3000-03b.dwg		CHECK	E.M.L.
PROJECT No. 09-1125-0005	REV. 0	REVIEW	D.G.M.

PWGSC, Wastewater Treatment Options
Eureka, Nunavut

FIGURE 4

PLOT DATE: April 6, 2009
FILENAME: N:\Active\2009\1125 - Environmental & Civil Engineering\09-1125-0005 PWGSC Eureka Wastewater\ACAD\Phase 3000\0911250005-3000-03b.dwg



LEGEND:

- SEWER LINE
- WATER LINE
- TEMPORARY / SEASONAL SEWAGE LINE

REFERENCES:

1. BASE PLAN PROVIDED IN ELECTRONIC FORMAT BY: PWGSC, PROJECT No. 422007, SHEET 1 OF 1, EUREKA SITE PLAN, DATED JULY 2008.

1. THIS DRAWING / FIGURE IS TO BE READ IN CONJUNCTION WITH GOLDER ASSOCIATES LTD. REPORT No. 09-1125-0005.

Golder Associates
Ottawa, Ontario, Canada

SCALE	1:1,250
DATE	12 Mar. 2009
DESIGN	E.M.L.
CAD	M.L.F.
CHECK	E.M.L.
REVIEW	D.G.M.
FILE No.	0911250005-3000-03b.dwg
PROJECT No.	09-1125-0005
REV.	0

TITLE

Conceptual Site Plan for New Lagoon Option 2

PWGSC, Wastewater Treatment Options
Eureka, Nunavut

FIGURE **5**

PLOT DATE: April 6, 2009
FILENAME: N:\Active\2009\1125 - Environmental & Civil Engineering\09-1125-0005 PWGSC Eureka Wastewater\ACAD\Phase 3000\0911250005-3000-03b.dwg

APPENDIX A
WATER BALANCE CALCULATIONS

2007 WATER BALANCE

Start Date: June/July 2006 (Pump fresh water into reservoir)
End Date: June 25, 2007 (Pump water out of sewage lagoon)

Fresh Water Reservoir Area	6,734	m2
Sewage Lagoon Area	1765	m2

	Amount	Units	Description	Source
Q1	2170.1	m3	Fresh Water Obtained	Based on pump capacity and time pumped from June 25 to July 13, 2007 - See Appendix A
Q2	673.4	m3	Evaporation/Sublimation - Reservoir	Hydrologic Atlas of Canada (AES, 1975)
Q3	2160.5	m3	Total Water Consumption	Total Month End tables - July 2007 to June 2008
Q4	1527.5	m3	Waste Water Discharged	Based on pump capacity and time pumped on July 4, 2007
Q5	1500.0	m3	MSC Water Consumption	MSC Month End tables - July 2007 to June 2008
Q6	517.2	m3	Precipitation - Reservoir	Environment Canada Climate Data Online, Eureka Weather Station
Q7	13.6	m3	Evaporation/Sublimation - Lagoon	Hydrologic Atlas of Canada (AES, 1975)
Q8	135.6	m3	Precipitation - Lagoon	Environment Canada Climate Data Online, Eureka Weather Station

	INS	=	**OUTS**	Notes Error
Ideally	Q1+Q6	=	Q2+Q3	
Reality	2687.3		2833.9	5.2%
Ideally	Q5+Q8	=	Q4+Q7+Q9	
Reality	1635.6		1541.0	-5.8%

Assumptions:
Pumping happens near the end of June/beginning of July each year
The fresh water reservoir is filled to the same level every year
The sewage lagoon is completely emptied each year
Water consumption is approximately equal to water discharge from the building

2007 WATER BALANCE

Start Date: June/July 2006 (Pump fresh water into reservoir)
End Date: June 25, 2007 (Pump water out of sewage lagoon)

Fresh Water Reservoir Area	6,734	m2
Sewage Lagoon Area	1765	m2

	Amount	Units	Description	Source
Q1	2170.1	m3	Fresh Water Obtained	Based on pump capacity and time pumped from June 25 to July 13, 2007 - See Appendix A
Q2	673.4	m3	Evaporation/Sublimation - Reservoir	Hydrologic Atlas of Canada (AES, 1975)
Q3	2160.5	m3	Total Water Consumption	Total Month End tables - July 2007 to June 2008
Q4	1527.5	m3	Waste Water Discharged	Based on pump capacity and time pumped on July 4, 2007
Q5	1500.0	m3	MSC Water Consumption	MSC Month End tables - July 2007 to June 2008
Q6	517.2	m3	Precipitation - Reservoir	Environment Canada Climate Data Online, Eureka Weather Station
Q7	13.6	m3	Evaporation/Sublimation - Lagoon	Hydrologic Atlas of Canada (AES, 1975)
Q8	135.6	m3	Precipitation - Lagoon	Environment Canada Climate Data Online, Eureka Weather Station

	INS	=	OUTS	Notes Error
Ideally	Q1+Q6	=	Q2+Q3	
Reality	2687.3		2833.9	5.2%
Ideally	Q5+Q8	=	Q4+Q7+Q9	
Reality	1635.6		1541.0	-5.8%

Assumptions:
Pumping happens near the end of June/beginning of July each year
The fresh water reservoir is filled to the same level every year
The sewage lagoon is completely emptied each year
Water consumption is approximately equal to water discharge from the building

APPENDIX B

TREATMENT TECHNOLOGY INFORMATION

Conventional Activated Sludge with Separate Clarifier

Whitewater® (Integrated Activated Sludge and Clarifier)

Sequencing Batch Reactor (SBR)

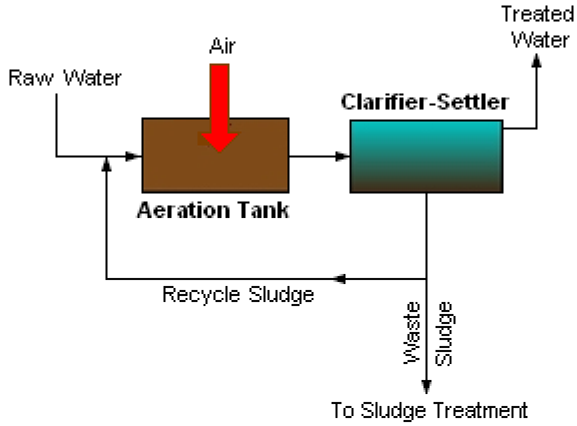
Rotating Biological Contactor (RBC)

Waterloo Biofilter® (Media-based Tricking Filter)

FAST® System (Submerged Fixed Film Bioreactor)

Facultative Lagoon

Conventional Activated Sludge with Separate Clarifier



Source: Wikipedia, 2007

Delta Environmental Products™

Pentair Water

A respected leader in wastewater treatment with more than 25 years of technical design and manufacturing experience. Delta is committed to the continuing development of new products to lead us into the 21st century.

Other Delta Products

CONTROL SERIES

DRIP SERIES

POD SERIES ADVANCED WASTEWATER TREATMENT

WHITEWATER SERIES

Sold only through local factory-trained distributors

WHITEWATER aerobic treatment units and accessories are sold, installed and serviced by certified Delta distributors who are fully trained to provide all necessary components and ensure a professional installation.

Delta Environmental Products

P.O. Box 969

8275 Florida Blvd. • Denham Springs, LA 70727

225-665-6162

www.deltaenvironmental.com

1 (800) 219-9183

Distributed by:

DLE-014

WHITEWATER SERIES

The Difference is Clear

Delta Environmental Products™

Pentair Water

NSF

Certified to ANSI/NSF Standard 40

Class I

ANSI ACCREDITED CERTIFICATION PROGRAM

NSF's certification Program is accredited by the American National Standards Institute

WHITEWATER SERIES

The Difference is Clear

by Delta Environmental Products

The Clear Choice for wastewater on-site disposal system is the WHITEWATER DF Series and UC Series Aerobic Treatment Unit (ATU). The WHITEWATER UC Series ATU was tested under standard 40 of ANSI/NSF International and met and exceeded Class I requirements with an average effluent quality of 6 mg/L BOD5 and 8 mg/L TSS.

How The WHITEWATER® Aerobic Treatment Unit Works

In using the Whitewater Aerobic Treatment Unit you can be proud that you are directly contributing to a cleaner, safer environment.

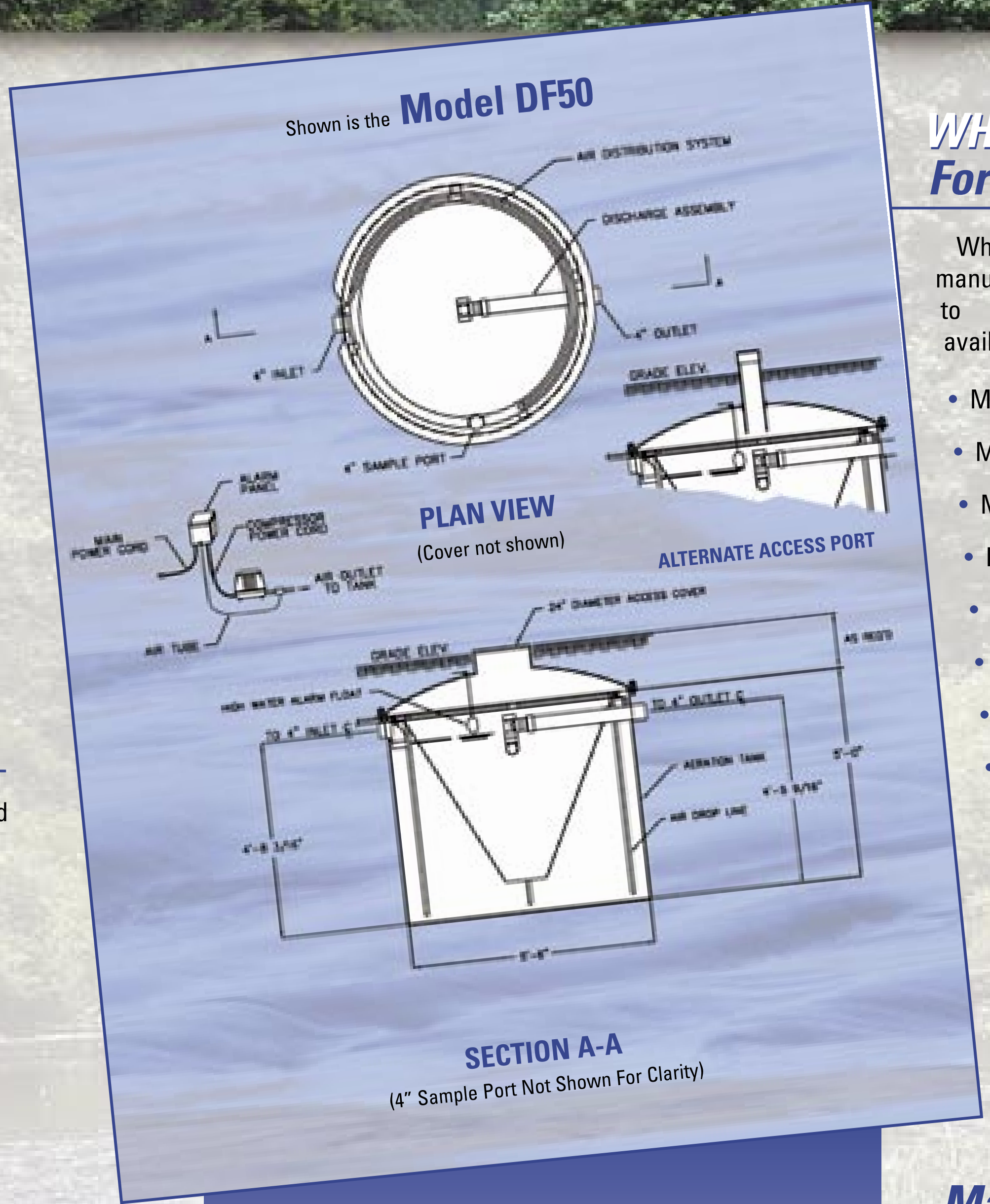
Whitewater works by using the bacteria nature provides. As a result of air being pumped into the system, the bacteria thrive and grow in much greater numbers than would occur naturally. This "overpopulation" of bacteria speeds the process of breaking down the sewage, making it safe for release into the environment.

The process occurs entirely within the self-contained Whitewater ATU which is comprised of an outer mixing tank and a cone-shaped settling chamber. Raw, unsettled domestic wastewater enters directly into the mixing tank where mixing occurs through an air distribution system.

The mixed liquid then enters the settling chamber from the bottom. The settling chamber maintains a quiet condition which allows solids to settle down and re-enter the mixing chamber for more processing. The liquid is hydraulically displaced upward and is discharged as clear, odorless treated water which meets or exceeds state water quality standards.

Why Use a WHITEWATER® Aerobic Treatment Unit?

- ANSI/NSF International Standard 40 Class 1 Certified
- Disposes of wastewater quietly, efficiently, and with no odor
- DF40, UC50 & DF50 operate on same power as a light bulb
- FHA and VA acceptable
- State approved and accepted by sanitarians
- Low initial capital cost & operation
- No inner tank filters, screens or diffusers to service
- For use where conventional septics are inadequate
- Unit provides 90% reduction of viruses; 99% reduction of viruses with disinfection
- 5/10 year limited warranty



Design Components Material Specifications

Shown above is the **Model DF50**

Treatment Capacity	**500 GPD**
Volumetric Capacity	**916 Gal**
Electrical Requirement	**85 Watts; 115/ 1/60**
Aerator-Whitewater Compressor	**DF50**

WHITEWATER® For Specific Uses

Whitewater Aerobic Treatment Units are manufactured to specifications according to wastewater flow requirements. Units are available in the following sizes:

- Model DF40 treating 400 gallons per day
- Model DF50 treating 500 gallons per day
- Model UC50 treating 500 gallons per day
- Model DF60 treating 600 gallons per day
- Model DF75 treating 750 gallons per day
- Model UC90 treating 900 gallons per day
- Model DF100 treating 1000 gallons per day
- Model UC120 treating 1200 gallons per day
- Model DF150 treating 1500 gallons per day

Where larger wastewater flow requirements are required, Whitewater Modular Systems are available.

Manufactured According to Need

Two choices of fabrication are offered, consistent with your preference or regulatory requirements:

- Solid fiberglass tank with fiberglass cover
- Concrete tank with concrete cover*

**Based on regional availability*

United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-99-073 September 1999

Wastewater Technology Fact Sheet
Sequencing Batch Reactors

DESCRIPTION

The sequencing batch reactor (SBR) is a fill-and-draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single "batch" reactor, treated to remove undesirable components, and then discharged. Equalization, aeration, and clarification can all be achieved using a single batch reactor. To optimize the performance of the system, two or more batch reactors are used in a predetermined sequence of operations. SBR systems have been successfully used to treat both municipal and industrial wastewater. They are uniquely suited for wastewater treatment applications characterized by low or intermittent flow conditions.

Fill-and-draw batch processes similar to the SBR are not a recent development as commonly thought. Between 1914 and 1920, several full-scale fill-and-draw systems were in operation. Interest in SBRs was revived in the late 1950s and early 1960s, with the development of new equipment and technology. Improvements in aeration devices and controls have allowed SBRs to successfully compete with conventional activated sludge systems.

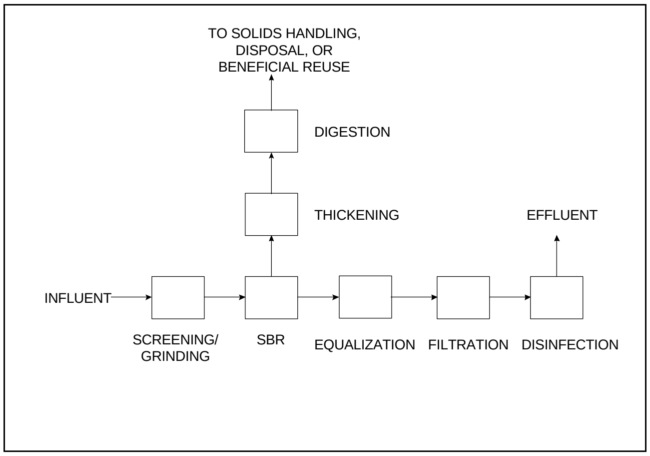
The unit processes of the SBR and conventional activated sludge systems are the same. A 1983 U.S. EPA report, summarized this by stating that "the SBR is no more than an activated sludge system which operates in time rather than in space." The difference between the two technologies is that the SBR performs equalization, biological treatment, and secondary clarification in a single tank using a timed control sequence. This type of reactor does, in some cases, also perform primary clarification. In a conventional activated sludge system, these unit processes would be accomplished by using separate tanks.

A modified version of the SBR is the Intermittent Cycle Extended Aeration System (ICEAS). In the ICEAS system, influent wastewater flows into the reactor on a continuous basis. As such, this is not a true batch reactor, as is the conventional SBR. A baffle wall may be used in the ICEAS to buffer this continuous inflow. The design configurations of the ICEAS and the SBR are otherwise very similar.

Description of a Wastewater Treatment Plant Using an SBR

A typical process flow schematic for a municipal wastewater treatment plant using an SBR is shown in Figure 1. Influent wastewater generally passes through screens and grit removal prior to the SBR. The wastewater then enters a partially filled reactor, containing biomass, which is acclimated to the wastewater constituents during preceding cycles. Once the reactor is full, it behaves like a conventional activated sludge system, but without a continuous influent or effluent flow. The aeration and mixing is discontinued after the biological reactions are complete, the biomass settles, and the treated supernatant is removed. Excess biomass is wasted at any time during the cycle. Frequent wasting results in holding the mass ratio of influent substrate to biomass nearly constant from cycle to cycle. Continuous flow systems hold the mass ratio of influent substrate to biomass constant by adjusting return activated sludge flowrates continually as influent flowrates, characteristics, and settling tank underflow concentrations vary. After the SBR, the "batch" of wastewater may flow to an equalization basin where the wastewater flowrate to additional unit processed can be is controlled at a determined rate. In some cases the wastewater is filtered to remove additional solids and then disinfected.

As illustrated in Figure 1, the solids handling system may consist of a thickener and an aerobic digester. With SBRs there is no need for return activated sludge (RAS) pumps and primary sludge (PS) pumps like those associated with conventional activated sludge systems. With the SBR, there is typically only one sludge to handle. The need for gravity thickeners prior to digestion is determined on a case by case basis depending on the characteristics of the sludge.



Source: Parsons Engineering Science, 1999.

FIGURE 1 PROCESS FLOW DIAGRAM FOR A TYPICAL SBR

An SBR serves as an equalization basin when the vessel is filling with wastewater, enabling the system to tolerate peak flows or peak loads in the influent and to equalize them in the batch reactor. In many conventional activated sludge systems, separate equalization is needed to protects the biological system from peak flows, which may wash out the biomass, or peak loads, which may upset the treatment process.

It should also be noted that primary clarifiers are typically not required for municipal wastewater applications prior to an SBR. In most conventional activated sludge wastewater treatment plants, primary clarifiers are used prior to the biological system. However, primary clarifiers may be recommended by the SBR manufacturer if the total suspended solids (TSS) or biochemical oxygen demand (BOD) are greater than 400 to 500 mg/L. Historic data should be evaluated and the SBR manufacturer consulted to determine whether primary clarifiers or equalization are recommended prior to an SBR for municipal and industrial applications.

Equalization may be required after the SBR, depending on the downstream process. If equalization is *not* used prior to filtration, the filters need to be sized in order to receive the batch of wastewater from the SBR, resulting in a large surface area required for filtration. Sizing filters to accept these “batch” flows is usually not feasible, which is why equalization is used between an SBR and downstream filtration. Separate equalization following the biological system is generally not required for most conventional activated sludge systems, because the flow is on a continuous and more constant basis.

APPLICABILITY

SBRs are typically used at flowrates of 5 MGD or less. The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flowrates.

As these systems have a relatively small footprint, they are useful for areas where the available land is limited. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary. This makes SBRs extremely flexible to adapt to regulatory changes for effluent parameters such as nutrient removal. SBRs are also very cost effective if treatment beyond biological treatment is required, such as filtration.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of SBRs are listed below:

Advantages

- Equalization, primary clarification (in most cases), biological treatment, and secondary clarification can be achieved in a single reactor vessel.

- Operating flexibility and control.

- Minimal footprint.

- Potential capital cost savings by eliminating clarifiers and other equipment.

Disadvantages

- A higher level of sophistication is required (compared to conventional systems), especially for larger systems, of timing units and controls.

- Higher level of maintenance (compared to conventional systems) associated with more sophisticated controls, automated switches, and automated valves.

- Potential of discharging floating or settled sludge during the DRAW or decant phase with some SBR configurations.

- Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer.

- Potential requirement for equalization after the SBR, depending on the downstream processes.

DESIGN CRITERIA

For any wastewater treatment plant design, the first step is to determine the anticipated influent characteristics of the wastewater and the effluent requirements for the proposed system. These influent parameters typically include design flow, maximum daily flow BOD_5, TSS, pH, alkalinity, wastewater temperature, total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), and total phosphorus (TP). For industrial and domestic wastewater, other site specific parameters may also be required.

The state regulatory agency should be contacted to determine the effluent requirements of the proposed plant. These effluent discharge parameters will be dictated by the state in the National Pollutant Discharge Elimination System (NPDES) permit. The parameters typically permitted for municipal systems are flowrate, BOD_5, TSS, and Fecal Coliform. In addition, many states are moving toward requiring nutrient removal. Therefore, total nitrogen (TN), TKN, NH_3-N, or TP may also be required. It is imperative to establish effluent requirements because they will impact the operating sequence of the SBR. For example, if there is a nutrient requirement and NH_3-N or TKN is required, then nitrification will be necessary. If there is a TN limit, then nitrification and denitrification will be necessary.

Once the influent and effluent characteristics of the system are determined, the engineer will typically consult SBR manufacturers for a recommended design. Based on these parameters, and other site specific parameters such as temperature, key design parameters are selected for the system. An example of these parameters for a wastewater system loading is listed in Table 1.

TABLE 1 KEY DESIGN PARAMETERS FOR A CONVENTIONAL LOAD

	Municipal	Industrial
Food to Mass (F:M)	0.15 - 0.4/day	0.15 - 0.6/day
Treatment Cycle Duration	4.0 hours	4.0 - 24 hours
Typically Low Water Level Mixed Liquor Suspended Solids	2,000-2,500 mg/L	2,000 - 4,000 mg/L
Hydraulic Retention Time	6 - 14 hours	varies

Source: AquaSBR Design Manual, 1995.

Once the key design parameters are determined, the number of cycles per day, number of basins, decant volume, reactor size, and detention times can be calculated. Additionally, the aeration equipment, decanter, and associated piping can then be sized.

Other site specific information is needed to size the aeration equipment, such as site elevation above mean sea level, wastewater temperature, and total dissolved solids concentration.

The operation of an SBR is based on the fill-and-draw principle, which consists of the following five basic steps: Idle, Fill, React, Settle, and Draw. More than one operating strategy is possible during most of these steps. For industrial wastewater applications, treatability studies are typically required to determine the optimum operating sequence. For most municipal wastewater treatment plants, treatability studies are not required to determine the operating sequence because municipal wastewater flowrates and characteristic variations are usually predictable and most municipal designers will follow conservative design approaches.

The Idle step occurs between the Draw and the Fill steps, during which treated effluent is removed and influent wastewater is added. The length of the Idle step varies depending on the influent flowrate and the operating strategy. Equalization is achieved during this step if variable idle times are used. Mixing to condition the biomass and sludge wasting can also be performed during the Idle step, depending on the operating strategy.

Influent wastewater is added to the reactor during the Fill step. The following three variations are used for the Fill step and any or all of them may be used depending on the operating strategy: static fill, mixed fill, and aerated fill. During static fill, influent wastewater is added to the biomass already present in the SBR. Static fill is characterized by no mixing or aeration, meaning that there will be a high substrate (food) concentration when mixing begins. A high food to microorganisms (F:M) ratio creates an environment favorable to floc forming organisms versus filamentous organisms, which provides good settling characteristics for the sludge. Additionally, static fill conditions favor organisms that produce internal storage products during high substrate conditions, a requirement for biological phosphorus removal. Static fill may be compared to using "selector" compartments in a conventional activated sludge system to control the F:M ratio.

Mixed fill is classified by mixing influent organics with the biomass, which initiates biological reactions. During mixed fill, bacteria biologically degrade the organics and use residual oxygen or alternative electron acceptors, such as nitrate-nitrogen. In this environment, denitrification may occur under these anoxic conditions. Denitrification is the biological conversion of nitrate-nitrogen to nitrogen gas. An anoxic condition is defined as an environment in which oxygen is not present and nitrate-nitrogen is used by the microorganisms as the electron acceptor. In a conventional biological nutrient removal (BNR) activated sludge system, mixed fill is comparable to the anoxic zone which is used for denitrification. Anaerobic conditions can also be achieved during the mixed fill phase. After the microorganisms use the nitrate-nitrogen, sulfate becomes the electron acceptor. Anaerobic conditions are characterized by the lack of oxygen and sulfate as the electron acceptor.

Aerated Fill is classified by aerating the contents of the reactor to begin the aerobic reactions completed in the React step. Aerated Fill can reduce the aeration time required in the React step.

The biological reactions are completed in the React step, in which mixed react and aerated react modes are available. During aerated react, the aerobic reactions initialized during aerated fill are completed and nitrification can be achieved. Nitrification is the conversion of ammonia-nitrogen to nitrite-nitrogen and ultimately to nitrate-nitrogen. If the mixed react mode is selected, anoxic conditions can be attained to achieve denitrification. Anaerobic conditions can also be achieved in the mixed react mode for phosphorus removal.

Settle is typically provided under quiescent conditions in the SBR. In some cases, gentle mixing during the initial stages of settling may result in a clearer effluent and a more concentrated settled sludge. In an SBR, there are no influent or effluent currents to interfere with the settling process as in a conventional activated sludge system.

The Draw step uses a decanter to remove the treated effluent, which is the primary distinguishing factor between different SBR manufacturers. In general, there are floating decanters and fixed decanters. Floating decanters offer several advantages over fixed decanters as described in the Tank and Equipment Description Section.

Construction

Construction of SBR systems can typically require a smaller footprint than conventional activated sludge systems because the SBR often eliminates the need for primary clarifiers. The SBR never requires secondary clarifiers. The size of the SBR tanks themselves will be site specific, however the SBR system is advantageous if space is limited at the proposed site. A few case studies are presented in Table 2 to provide general sizing estimates at different flowrates. Sizing of these systems is site specific and these case studies do not reflect every system at that size.

TABLE 2 CASE STUDIES FOR SEVERAL SBR INSTALLATIONS

Flow	Reactors			Blowers	
(MGD)	No.	Size (feet)	Volume (MG)	No.	Size (HP)
0.012	1	18 x 12	0.021	1	15
0.10	2	24 x 24	0.069	3	7.5
1.2	2	80 x 80	0.908	3	125
1.0	2	58 x 58	0.479	3	40
1.4	2	69 x 69	0.678	3	60
1.46	2	78 x 78	0.910	4	40
2.0	2	82 x 82	0.958	3	75
4.25	4	104 x 80	1.556	5	200
5.2	4	87 x 87	1.359	5	125

Note: These case studies and sizing estimates were provided by Aqua-Aerobic Systems, Inc. and are site specific to individual treatment systems.

The actual construction of the SBR tank and equipment may be comparable or simpler than a conventional activated sludge system. For Biological Nutrient Removal (BNR) plants, an SBR eliminates the need for return activated sludge (RAS) pumps and pipes. It may also eliminate the need for internal Mixed Liquor Suspended Solid (MLSS) recirculation, if this is being used in a conventional BNR system to return nitrate-nitrogen.

The control system of an SBR operation is more complex than a conventional activated sludge system and includes automatic switches, automatic valves, and instrumentation. These controls are very sophisticated in larger systems. The SBR manufacturers indicate that most SBR installations in the United States are used for smaller wastewater systems of less than two million gallons per day (MGD) and some references recommend SBRs only for small communities where land is limited. This is not always the case, however, as the largest SBR in the world is currently a 10 MGD system in the United Arab Emirates.

Tank and Equipment Description

The SBR system consists of a tank, aeration and mixing equipment, a decanter, and a control system. The central features of the SBR system include the control unit and the automatic switches and valves that sequence and time the different operations. SBR manufacturers should be consulted for recommendations on tanks and equipment. It is typical to use a complete SBR system recommended and supplied by a single SBR manufacturer. It is possible, however, for an engineer to design an SBR system, as all required tanks, equipment, and controls are available through different manufacturers. This is not typical of SBR installation because of the level of sophistication of the instrumentation and controls associated with these systems.

The SBR tank is typically constructed with steel or concrete. For industrial applications, steel tanks coated for corrosion control are most common while concrete tanks are the most common for municipal treatment of domestic wastewater. For mixing and aeration, jet aeration systems are typical as they allow mixing either with or without aeration, but other aeration and mixing systems are also used. Positive displacement blowers are typically used for SBR design to handle wastewater level variations in the reactor.

As previously mentioned, the decanter is the primary piece of equipment that distinguishes different SBR manufacturers. Types of decanters include floating and fixed. Floating decanters offer the advantage of maintaining the inlet orifice slightly below the water surface to minimize the removal of solids in the effluent removed during the DRAW step. Floating decanters also offer the operating flexibility to vary fill-and-draw volumes. Fixed decanters are built into the side of the basin and can be used if the Settle step is extended. Extending the Settle step minimizes the chance that solids in the wastewater will float over the fixed decanter. In some cases, fixed decanters are less expensive and can be designed to allow the operator to lower or raise the level of the decanter. Fixed decanters do not offer the operating flexibility of the floating decanters.

Health and Safety

Safety should be the primary concern in every design and system operation. A properly designed and operated system will minimize potential health and safety concerns. Manuals such as the Manual of Practice (MOP) No. 8, Design of Municipal Wastewater Treatment Plants, and MOP No. 11, Operation of Municipal Wastewater Treatment Plants should be consulted to minimize these risks. Other appropriate industrial wastewater treatment manuals, federal regulations, and state regulations should also be consulted for the design and operation of wastewater treatment systems.

PERFORMANCE

The performance of SBRs is typically comparable to conventional activated sludge systems and depends on system design and site specific criteria. Depending on their mode of operation, SBRs can achieve good BOD and nutrient removal. For SBRs, the BOD removal efficiency is generally 85 to 95 percent.

SBR manufacturers will typically provide a process guarantee to produce an effluent of less than:

- 10 mg/L BOD
- 10 mg/L TSS
- 5 - 8 mg/L TN
- 1 - 2 mg/L TP

OPERATION AND MAINTENANCE

The SBR typically eliminates the need for separate primary and secondary clarifiers in most municipal systems, which reduces operations and maintenance requirements. In addition, RAS pumps are not required. In conventional biological nutrient removal systems, anoxic basins, anoxic zone mixers, toxic basins, toxic basin aeration equipment, and internal MLSS nitrate-nitrogen recirculation pumps may be necessary. With the SBR, this can be accomplished in one reactor using aeration/mixing equipment, which will minimize operation and maintenance requirements otherwise be needed for clarifiers and pumps.

Since the heart of the SBR system is the controls, automatic valves, and automatic switches, these systems may require more maintenance than a conventional activated sludge system. An increased level of sophistication usually equates to more items that can fail or require maintenance. The level of sophistication may be very advanced in larger SBR wastewater treatment plants requiring a higher level of maintenance on the automatic valves and switches.

Significant operating flexibility is associated with SBR systems. An SBR can be set up to simulate any conventional activated sludge process, including BNR systems. For example, holding times in the Aerated React mode of an SBR can be varied to achieve simulation of a contact stabilization system with a typical hydraulic retention time (HRT) of 3.5 to 7 hours or, on the other end of the spectrum, an extended aeration treatment system with a typical HRT of 18 to 36 hours. For a BNR plant, the aerated react mode (oxic conditions) and the mixed react modes (anoxic conditions) can be alternated to achieve nitrification and denitrification. The mixed fill mode and mixed react mode can be used to achieve denitrification using anoxic conditions. In addition, these modes can ultimately be used to achieve an anaerobic condition where phosphorus removal can occur. Conventional activated sludge systems typically require additional tank volume to achieve such flexibility. SBRs operate in time rather than in space and the number of cycles per day can be varied to control desired effluent limits, offering additional flexibility with an SBR.

COSTS

This section includes some general guidelines as well as some general cost estimates for planning purposes. It should be remembered that capital and construction cost estimates are site-specific.

Budget level cost estimates presented in Table 3 are based on projects that occurred from 1995 to 1998. Budget level costs include such as the blowers, diffusers, electrically operated valves, mixers, sludge pumps, decanters, and the control panel. All costs have been updated to March 1998 costs, using an ENR construction cost index of 5875 from the March 1998 Engineering News Record, rounded off to the nearest thousand dollars.

TABLE 3 SBR EQUIPMENT COSTS BASED ON DIFFERENT PROJECTS

Design Flowrate (MGD)	Budget Level Equipment Costs ($)
0.012	94,000
0.015	137,000
1.0	339,000
1.4	405,000
1.46	405,000
2.0	564,000
4.25	1,170,000

Source: Aqua Aerobics Manufacturer Information, 1998.

In Table 4, provided a range of equipment costs for different design flowrates is provided.

TABLE 4 BUDGET LEVEL EQUIPMENT COSTS BASED ON DIFFERENT FLOW RATES

Design Flowrate (MGD)	Budget Level Equipment Costs ($)
1	150,000 - 350,000
5	459,000 - 730,000
10	1,089,000 - 1,370,000
15	2,200,000
20	2,100,000 - 3,000,000

Note: Budget level cost estimates provided by Babcock King - Wilkinson, L.P., August 1998.

Again the equipment cost items provided do not include the cost for the tanks, sitework, excavation/backfill, installation, contractor's overhead and profit, or legal, administrative, contingency, and engineering services. These items must be included to calculate the overall construction costs of an SBR system. Costs for other treatment processes, such as screening, equalization, filtration, disinfection, or aerobic digestion, may be included if required.

The ranges of construction costs for a complete, installed SBR wastewater treatment system are presented in Table 5. The variances in the estimates are due to the type of sludge handling facilities and the differences in newly constructed plants versus systems that use existing plant facilities. As such, in some cases these estimates include other processes required in an SBR wastewater treatment plant.

TABLE 5 INSTALLED COST PER GALLON OF WASTEWATER TREATED

Design Flowrate (MGD)	Budget Level Equipment Cost ($/gallon)
0.5 - 1.0	1.96 - 5.00
1.1 - 1.5	1.83 - 2.69
1.5 - 2.0	1.65 - 3.29

Note: Installed cost estimates obtained from Aqua-Aerobics Systems, Inc., August 1998.

There is typically an economy of scale associated with construction costs for wastewater treatment, meaning that larger treatment plants can usually be constructed at a lower cost per gallon than smaller systems. The use of common wall construction for larger treatment systems, which can be used for square or rectangular SBR reactors, results in this economy of scale.

Operations and Maintenance (O&M) costs associated with an SBR system may be similar to a conventional activated sludge system. Typical cost items associated with wastewater treatment systems include labor, overhead, supplies, maintenance, operating administration, utilities, chemicals, safety and training, laboratory testing, and solids handling. Labor and maintenance requirements may be reduced in SBRs because clarifiers, clarification equipment, and RAS pumps may not be necessary. On the other hand, the maintenance requirements for the automatic valves and switches that control the sequencing may be more intensive than for a conventional activated sludge system. O&M costs are site specific and may range from $800 to $2,000 dollars per million gallons treated.

REFERENCES

1. *AquaSBR Design Manual*. Mikkelson, K.A. of Aqua-Aerobic Systems. Copyright 1995.

2. Arora, Madan L. *Technical Evaluation of Sequencing Batch Reactors*. Prepared for U.S. EPA. U.S. EPA Contract No. 68-03-1821.

3. *Engineering News-Record*. A publication of the McGraw Hill Companies, March 30, 1998.

4. Irvine, Robert L. *Technology Assessment of Sequencing Batch Reactors*. Prepared for U.S. EPA. U.S. EPA Contract No. 68-03-3055.

5. Liu, Liptak, and Bouis. *Environmental Engineer's Handbook*, 2nd edition. New York: Lewis Publishers.

6. *Manufacturers Information.* Aqua-Aerobics, Babcock King-Wilkinson, L.P., Fluidyne, and Jet Tech Systems, 1998.

7. Metcalf & Eddy, Inc. *Wastewater Engineering: Treatment, Disposal, Reuse.* 3rd edition. New York: McGraw Hill.

8. Parsons Engineering Science, Inc. *Basis of Design Report - Urgent Extensions to Maray Sewer Treatment Works*, Abu Dhabi, UAE, 1992.

9. Norcross, K.L., *Sequencing Batch Reactors - An Overview*. Technical Paper published in the IAWPRC 1992 (0273-1221/92). Wat. Sci. Tech., Vol. 26, No. 9-11, pp. 2523 - 2526.

10. Peavy, Rowe, and Tchobanoglous: *Environmental Engineering*. New York: McGraw-Hill, Inc.

11. U.S. EPA. *Innovative and Alternative Technology Assessment Manual*, EPA/430/9-78-009. Cincinnati, Ohio, 1980.

12. U.S. EPA. EPA Design Manual, Summary Report *Sequencing Batch Reactors*. EPA/625/8-86/011, August 1986.

13. Manual of Practice (MOP) No. 8, Design of Municipal Wastewater Treatment Plants,

14. Manual of Practice (MOP) No. 11, Operation of Municipal Wastewater Treatment Plants.

ADDITIONAL INFORMATION

Brad Holtsinger, Chief Operator
City of Stockbridge WWTP
4545 North Henry Boulevard
Stockbridge, GA 30281

Gary Hooder, Operator
Martinsburg WWTP
133 East Allegheny
Martinsburg, PA 16662-1112

Mitchell Meadows, Lead Operator
1300 Recker Highway
Auburndale, FL 33823

Teresa Schnoor, Administrator
Antrim TWP
P.O. Box 130
Greencastle, PA 17225

Charles Sherrod, Chief Operator
Blountstown WWTP
125 West Central Avenue
Blountstown, FL 32424

For more information contact:

Municipal Technology Branch
U.S. EPA
Mail Code 4204
401 M St., S.W.
Washington, D.C., 20460

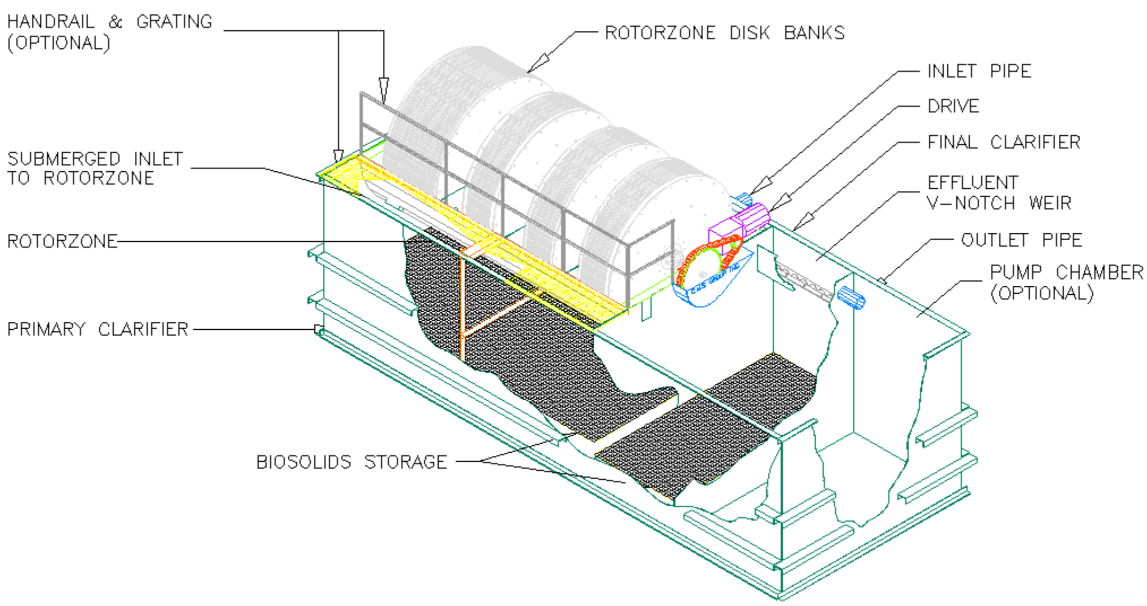
OWM MTB

Excellence in compliance through optimal technical solutions

MUNICIPAL TECHNOLOGY BRANCH

1. ROTORDISK® B50: PROCESS DESCRIPTION

1.1 Process Description of the ROTORDISK® B50 Wastewater Treatment Plant



1.2 Process Details

This wastewater treatment technology utilizes a fixed growth bacteria process whereby bacteria are grown on a media surface that is rotated into and out of the wastewater. The treated wastewater flows through four zones each with a progressively higher standard of treatment. Unlike most suspended growth bioreactors, the ROTORDISK® is not prone to upsets and can be operated with very low flows during early years of site development. The system can be operated from near zero influent to above design capacity for intermittent periods. The system is free of unpleasant odours and can be located directly within built up areas thereby minimizing piping requirements.

Operating Life. The typical operating life of a ROTORDISK® is 25 years under conditions of normal use. Seprotech has installations in place that have been in continuous operation since 1974.

Delivery to Site. This ROTORDISK® B50 Wastewater Treatment plant is delivered to the site partially disassembled into major assemblies, that will require minimal installation time, before the plant is ready for start-up and commissioning. The tank is backfilled (if desired), an insulated cover is placed over the equipment and the plant is essentially ready to be started. The intent is to deliver as complete an operating package as possible.

Bacteria Growth. ROTORDISK® employs engineered plastic disks made from grid extruded medium density polyethylene material with U.V. light inhibitors. This is the media on which bacteria grow. The grid pattern promotes oxygen transfer into the wastewater and particularly into the core of the media. The assembly is specially designed to prevent anaerobic conditions from developing. Bacteria that are present in the environment grow naturally on the media. Bacteria growth and contraction is a natural process that is governed by the quantity and type of wastewater flow into the plant.

A major advantage to a ROTORDISK® plant is that the serpentine flow through four zones creates tremendous bacteriological biodiversity along the length of the Rotating Assembly. This biodiversity leads to extremely efficient consumption of the biomass as a result of which, much less sludge is produced than in a suspended growth bioreactor. Up to four times less sludge is produced in a ROTORDISK®.

Handling Odours. Wastewater can only become odorous in the absence of oxygen. These are called anaerobic conditions. Anaerobic processes, such as septic tanks, tend to be associated with very strong smells and these are unavoidable with such processes. The ROTORDISK® employs an aerobic process. This means that the entire process is done in the presence of oxygen. The ROTORDISK® is a very heavily aerated process and is therefore extremely stable and not prone to becoming septic. Aerobic processes typically do not have a pungent sewage stench but have more of a light musty odour. This light musty odour is not detectable by persons 3 meters from the walls of the operating facility. The Seprotech solution therefore creates an environment that is not unpleasant for operators and permits the locating of the facility in built-up areas. The main process is therefore without unpleasant odours.

Materials of Construction. The ROTORDISK® trough is semi-circular and fabricated from ¼" steel plate. All metal surfaces are sand blasted to SSPC-SP-10-63 white metal and painted with one coat of primer and two coats of Devtar-5A to a minimum of 16 mil.

The banks of media are contained between rigid woven mat FRP endplates, supported by tension rods and polyethylene spacers.

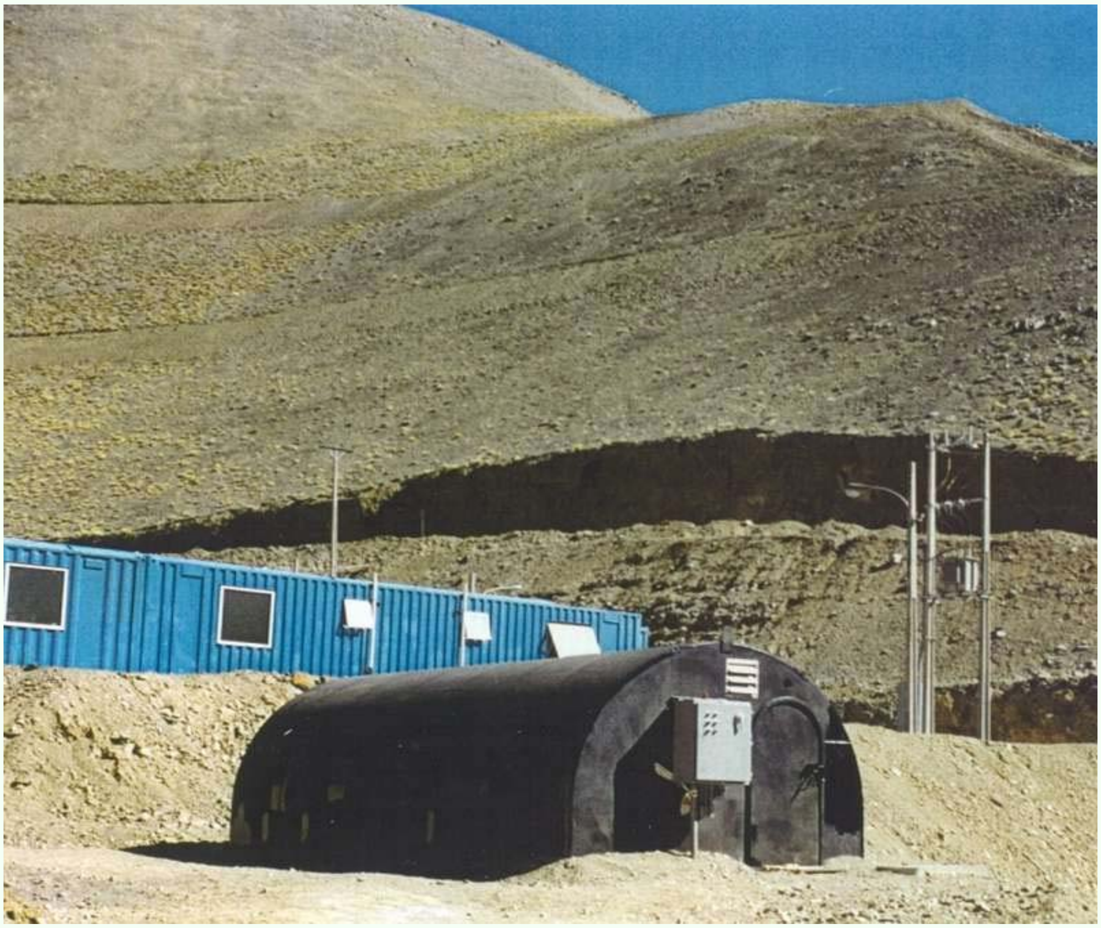
The drive train is comprised of an Electric Motor, Double Reduction Gearbox, Bearings, Chain and Sprocket, and is pre-assembled at the factory. The motor is T.E.F.C. for use in high moisture conditions, C-flanged, and is equal to or surpasses the NEMA C high torque specs.

The reducer is a double reduction helical bevelled unit, lubricated for a minimum of five (5) years and sealed for high humidity service. The bearings are spherical roller, self- aligning, split pillow block.

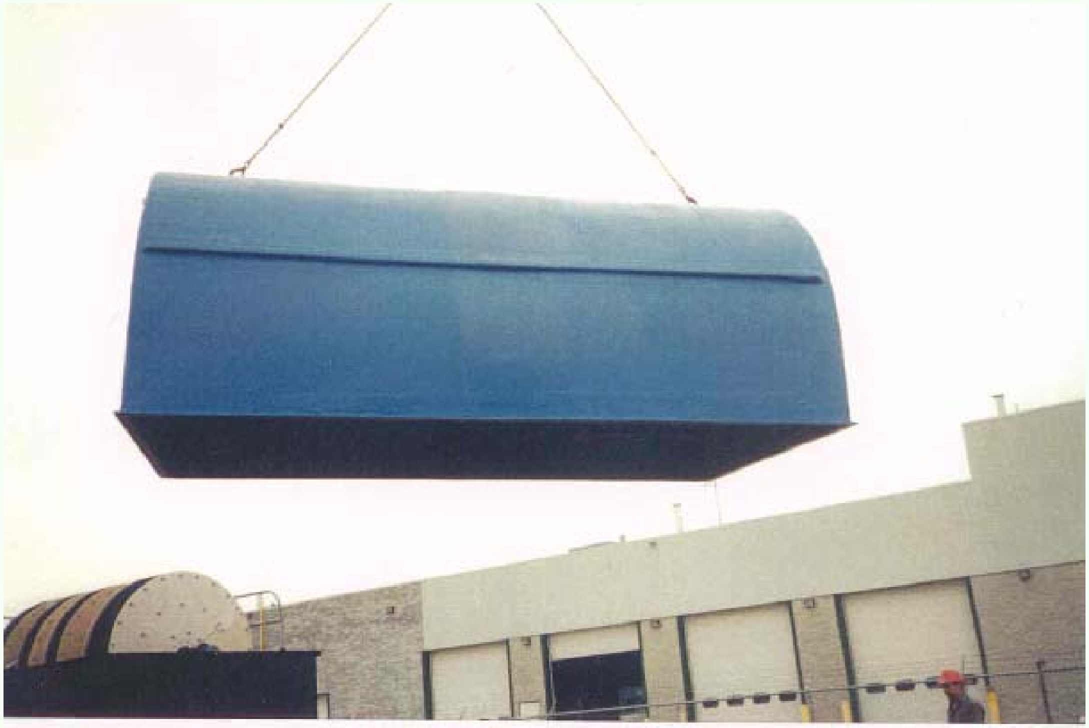
SELECTED PHOTOGRAPHS

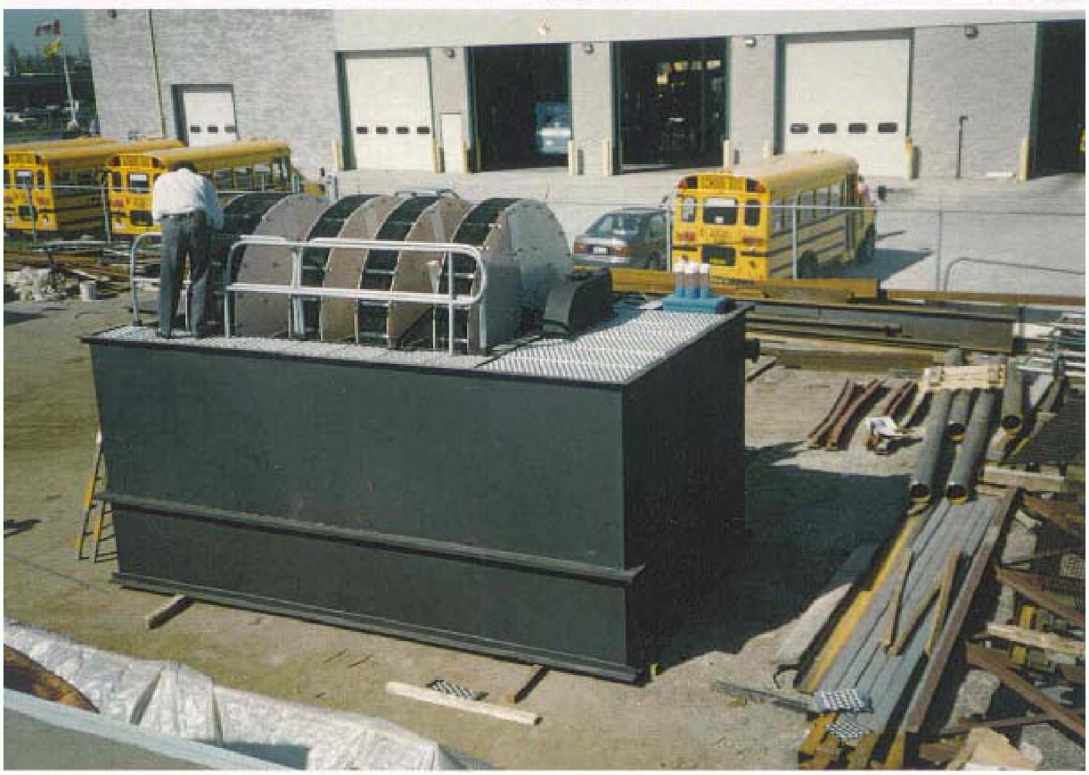
Barrick Gold, Alto Chicama Mine Site (Below Grade Installation)

EL INDIO, CHILE – TORO MUERTO MINE CAMP



GETCHELL GOLD MINE, NEVADA





HOLT McDERMOTT MINE SITE, KIRKLAND, ONTARIO

MARICUNGA MINE SITE, CHILE

TRANSPORT OF COVER AND ROTORDISK® ACCESSORIES

SKYWAY INDUSTRIAL PARK, ONTARIO

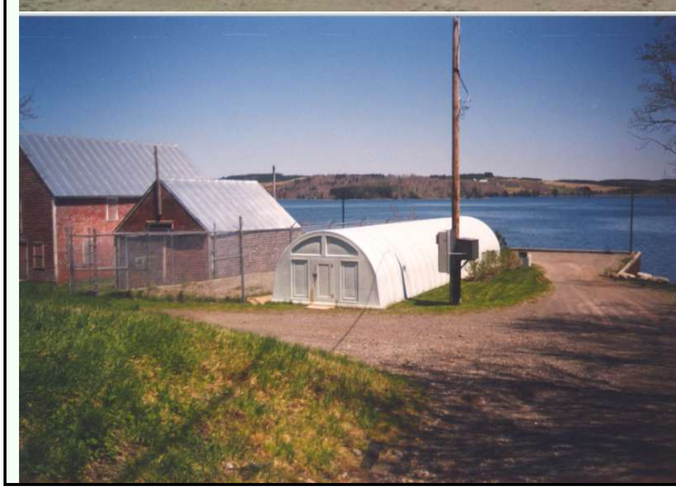
TRANSPORTATION OF FULL STEEL ROTORDISK® FROM THE FACTORY

EXAMPLE OF USE OF MULTIPLE UNITS IN PARALLEL

CITY OF BARRIE, MUNICIPAL WASTEWATER TREATMENT PLANT

New Horizon (200 Home Subdivision), Everett, Ontario

Examples of Custom Building Styles



Vankleek Hill, Ontario

On-site Wastewater Treatment for

Commercial & Communal

Modified ISO Shipping Containers...

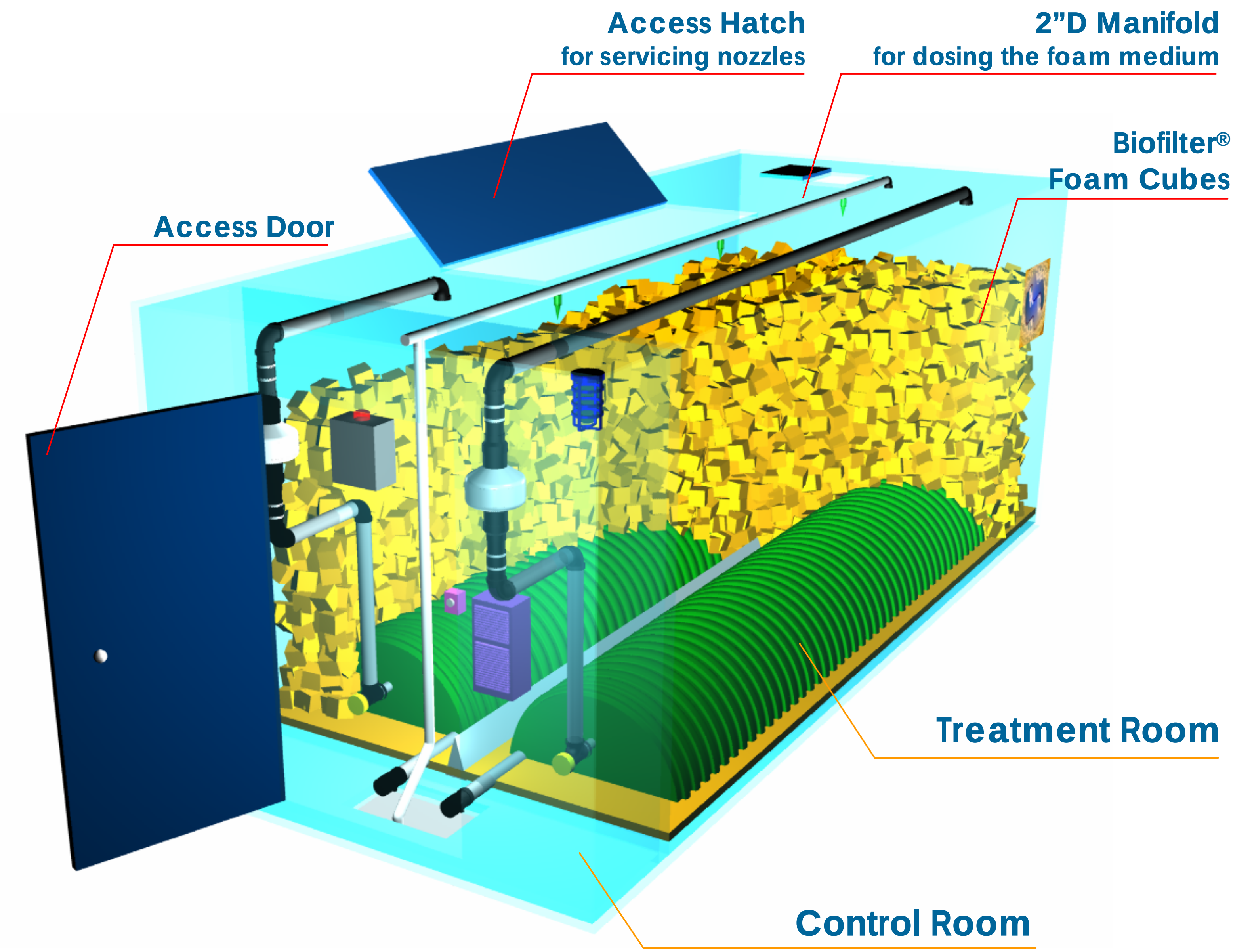
SC-20 & SC-40

Waterloo Biofilter Systems Inc.

The SC Unit

The Shipping Container (SC) Unit is a standard ISO container customized into a integrated Waterloo Biofilter®, which is comprised of two chambers, the treatment room and the control room. The treatment room houses the patented foam medium and a drainage system that allows for 50% recirculation of the effluent to the septic tank. The control room contains 2 control panels that control the dosing and disposal pumps, rheostat-controlled air fans that improve ventilate the filter medium, and an optional space heater. The SC Unit is available in two sizes, 20 and 40 feet long, SC-20 and SC-40 respectively.

Inside of SC-20...



SC Features

Easy Installation & Maintenance Requires minimal on-site assembly. Lockable roof hatches allow for easy maintenance of spray nozzles. Control room includes air fans, plumbing and control panels for servicing.

High Strength Wastewater The SC Unit can treat commercial wastewater when designed properly and when care is taken when using chemicals in the facility.

Subsurface or Surface Disposal Can provide phosphorus, ammonium, and pathogen removal as required for surface disposal, including re-use of treated sewage for irrigation and even toilet flushing.

Modular Can be connected in parallel for scaling up or for multiple phase projects.

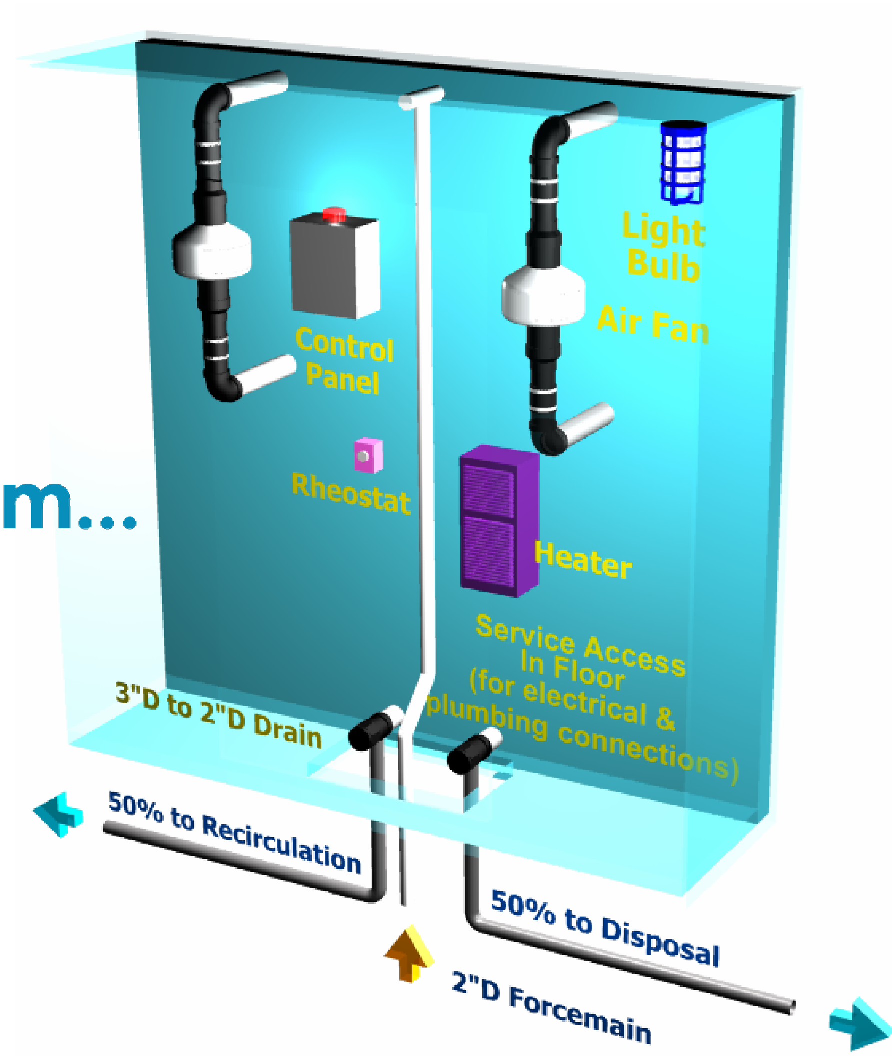
Customizable Available in a variety of custom colours.

Transportable by land or sea as standard ISO shipping container.

Rated Capacity

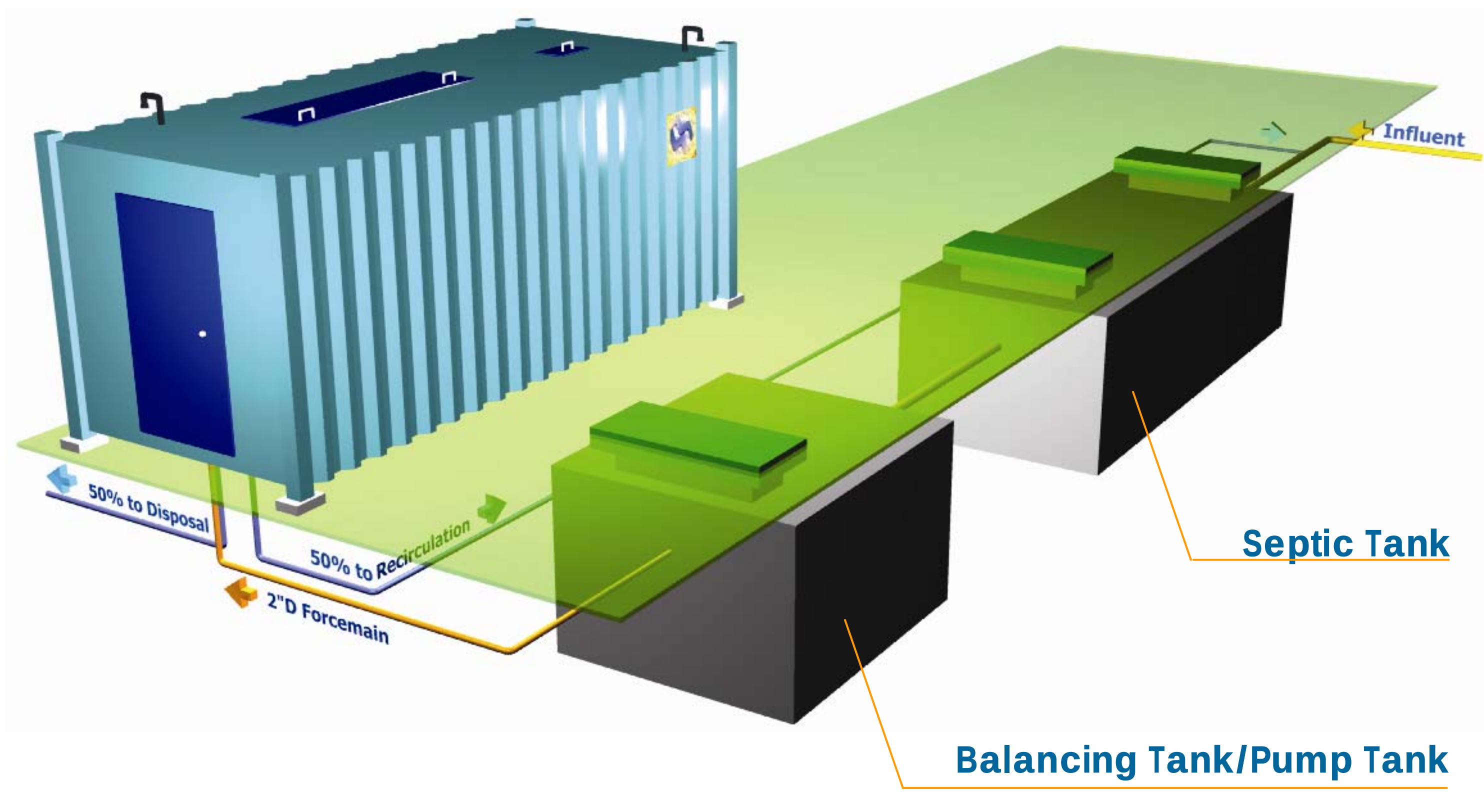
	Dimensions L x W x H	Treatment Capability [L/d] Loading Rate [L/m³/d] 375	500	750
SC-20	20' x 8' x 8.5'	10,000	13,350	20,000
SC-40	40' x 8' x 8.5'	20,000	26,700	40,000

Inside the Control Room...

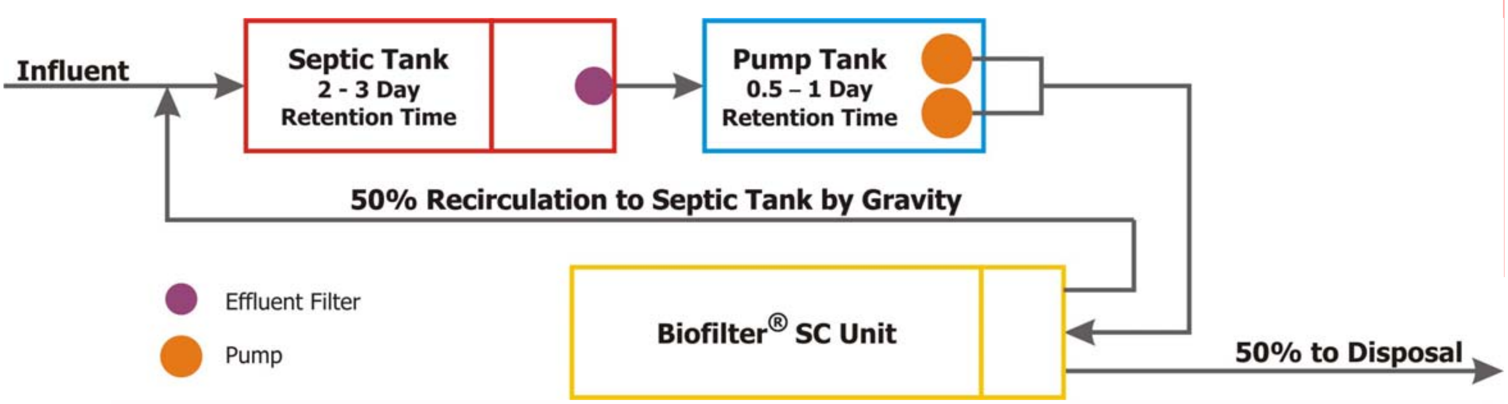


Waterloo Biofilter Systems Inc.

System Overview



Process Schematic



Waterloo Biofilter Systems Inc.
on-site wastewater treatment
143 Dennis Street, PO Box 400 Rockwood ON N0B 2K0
T: 519.856.0757 | F: 519.856.0759 | wbs@waterloo-biofilter.com | www.waterloo-biofilter.com

BIO-MICROBICS®
INCORPORATED

Better Water. Better World.®

FAST® with SFR®
wastewater
treatment
systems

Wastewater Treatment for a Changing World

The world's population is growing and the increased demand on water resources has forced lifestyle changes and an emphasis on water conservation. Although water conservation helps to preserve our precious water resources, conservation also makes concentrations of pollutants stronger in wastewater. Additionally, new chemicals introduced into the waste stream everyday from agricultural, industrial and pharmaceutical industries make it more challenging to treat water than ever before.

FAST® wastewater treatment systems are proven, innovative treatment products that provide robust, high-performance treatment to meet the challenges of our changing world. Suited for use in countless applications, a versatile FAST system is ready to serve your needs. FAST® is designed to be efficient, dependable, easy to install and very user-friendly. FAST is tremendously beneficial alone or in combination with other processes to meet the rigorous demands of the most challenging and complex projects. Retrofitting of existing activated sludge plants with FAST technology is an affordable, dependable way to significantly upgrade performance with minimal impact in time and operation.

LagoonFAST Wastewater Treatment Systems

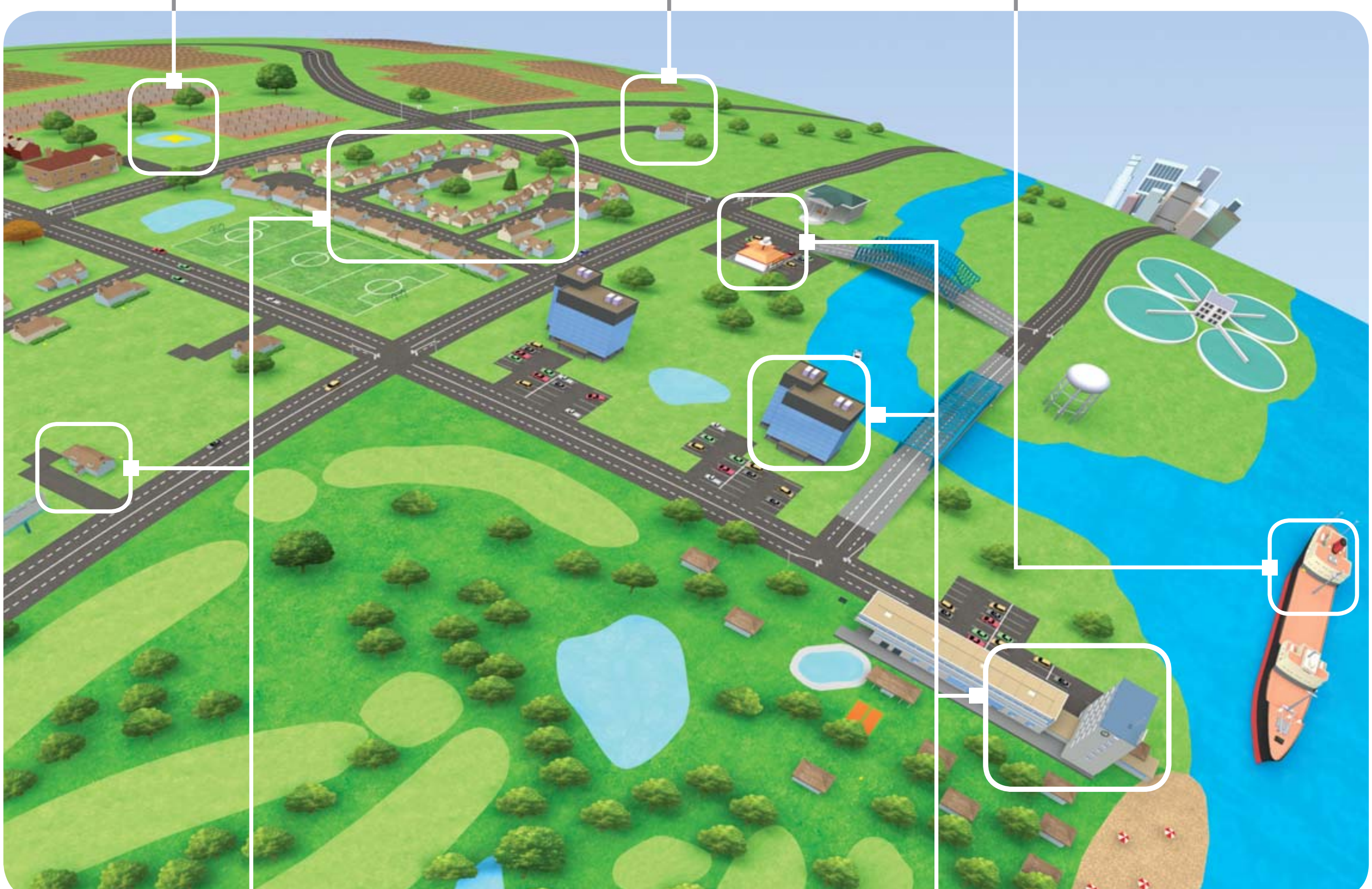
Clever upgrade packages for high-performance treatment and enhanced nitrification of aeration ponds and lagoons.

RetroFAST wastewater treatment systems

Simple retrofit for conventional septic systems. Renovates failing systems, upgrades new systems.

MarineFAST's complete line of proven marine sanitation devices, packaged for large and small marine vessels, such as: yachts, work boats, offshore rigs and more.

SCIENCO/FAST



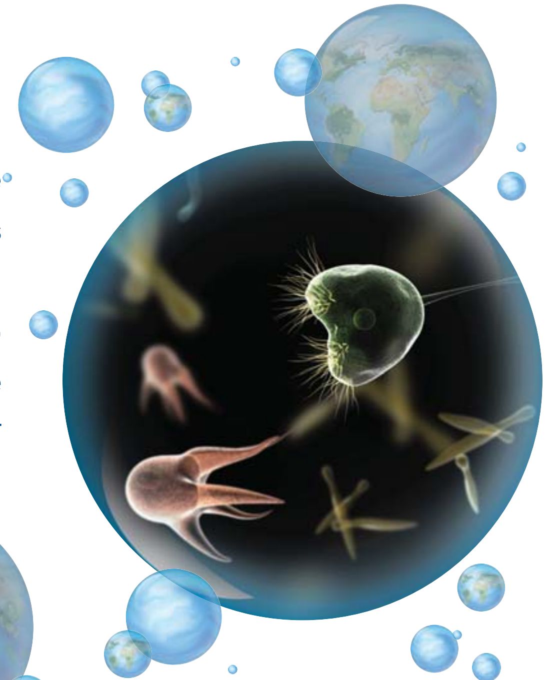
MicroFAST wastewater treatment systems

Advanced wastewater treatment systems for individual homes, clustered subdivisions, small communities and other sanitary-strength flow applications. Simple installation, proven performance.

HighStrengthFAST wastewater treatment systems

Meeting the unique challenges of high-strength commercial applications with robust, low-maintenance treatment modules.

The Real Beauty of this System is How Well it Works.



FAST® is simply great technology, based on environmentally sound and simple scientific principles. The FAST (Fixed Activated Sludge Treatment) process employs a unique hybrid combination of attached and suspended growth in an aerobic, packed bed bioreactor. This proven IFAS (Integrated Fixed-Film Activated Sludge) combination includes the stability of fully-submerged, fixed-film media and the effectiveness of activated sludge treatment, making the innovative, patented FAST system technologically advanced and extraordinarily reliable. The FAST process provides the ideal environment for rapid bacterial growth by ensuring plenty of oxygen and food are equally distributed to the bacteria layered upon the surfaces of the media.

FAST's fixed film media provides a high surface-to-volume ratio to maintain exceptional microbial growth during low, average and peak usage. Bacteria become "fixed" or attached to the stationary media where the abundant, diverse and self-regulating population of microbes is consistently maintained in the aeration zone to metabolize the waste. FAST maintains stable performance because the abundant bacterial population is attached to the media and does not wash out of the aeration zone. During times of low usage, the large volumes of thriving organisms delay a dying-off of the system, making FAST well suited to intermittent use applications. Unlike conventional activated-sludge (suspended-growth systems), bacteria grow on the media and feed on incoming waste, leaving the circulated liquid essentially clear and free of solids.

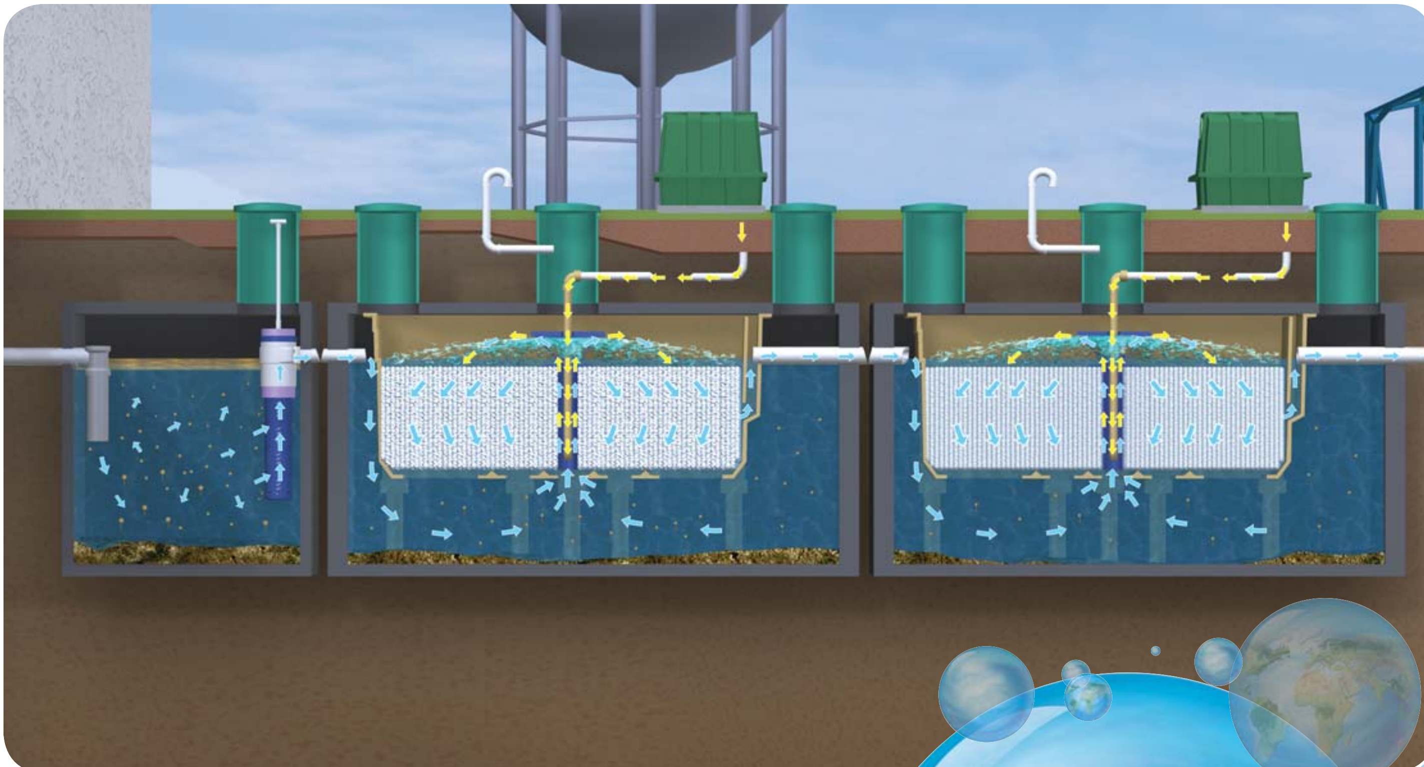
[The "fixed" bacteria feed off incoming waste, leaving the circulated liquid essentially clear and free of solids.]

A remote-mounted, above-ground blower, the systems only moving part, introduces air (oxygen) into the system to facilitate a robust circulation of wastewater through the media's channeled flow path. Eventually, the robust circulation of air and liquid through the system creates a sloughing effect on the thick biomass growth, which creates a self-cleaning action, eliminating the need for any media maintenance. Sloughed solids then settle to the bottom of the tank for later removal.

[The robust circulation creates a sloughing effect on the thick biomass growth...eliminating the need for any media maintenance.]

High levels of bacteria and other useful microbes (including stalked ciliates and rotifers) in the bioreactor aeration zone provide stable operation, break down biodegradable constituents in the wastewater, prevent bulking conditions and settling problems, and yield a significantly longer sludge age than conventional plants. A long sludge age achieves nitrification and denitrification much easier, operates more effectively in cold climates, and produces less sludge.

A FAST® system provides an ideal home for large volumes of friendly organisms in the inner, aerated, self-cleaning bioreactor chamber to digest the wastewater and turn it into a clear, odorless, high-quality effluent.



HighStrengthFAST Shown

FAST® wastewater treatment systems have proven themselves to consistently reduce nitrogen levels – including nitrates and all other nitrogen species - at exceptionally high percentage rates.

Nitrogen Reduction

Nitrification and denitrification projects are much easier with FAST technology. Multiple biological, bio-chemical, chemical and physical processes occur simultaneously within the FAST wastewater treatment system. Individual mechanisms may vary depending on the particular FAST product used and the specific needs of the project.

The very high surface area to volume ratio of the media provides the needed space for nitrifying bacteria to attach themselves within the naturally protective environment of the fixed film micro sites. Large volumes of biomass, combined with longer sludge age, lessen the impact of low temperature effects, further enabling a more complete nitrification of influent ammonia levels.

FAST wastewater treatment systems have proven themselves to consistently reduce nitrogen levels – including nitrates and all other nitrogen species - at exceptionally high percentage rates. Larger or more complex applications can also utilize various configurations of FAST in combination with other processes to meet the rigorous demands of the most challenging projects.

Decades of experience with water and wastewater projects worldwide has taught us that when we provide pre-engineered, modularized products to project decision makers, projects are completed more quickly, more affordably and with repeatable, consistent and successful results.

FAST® is designed to be efficient, dependable, easy to install and very user-friendly. FAST is tremendously beneficial alone or in combination with other processes to meet the rigorous demands of the most challenging and complex projects.

- Retrofitting of existing activated sludge plants with FAST technology is an affordable, dependable way to significantly upgrade performance with minimal impact in time and operation.
- The advanced treatment of FAST allows for innovative reuse and recycling of precious water resources.
- Aerated ponds and lagoons can also be considerably enhanced with the addition of specially configured FAST systems designed for installation directly into the lagoon without missing a day of operation.
- The flexibility and consistent performance of the compact, modular FAST wastewater treatment systems make them ideal for use in countless applications and projects around the world.
- Since the first FAST prototype installation aboard the river towboat M/V Missouri in 1969, FAST® products can now be seen operating quietly in residential, commercial, municipal, industrial and marine applications around the globe.

A Process Born from Unique Challenges

Since the early 1900s, wastewater engineers have attempted to use some form of medium in an aerobic environment to facilitate biomass growth and reduction of solids and BOD in domestic and industrial wastewater. In the 1960s, Smith & Loveless, Inc. succeeded in developing a version of this hybrid process and engineered a new technology called fixed activated sludge treatment (FAST®) for the marine industry. This innovative system allowed wastewater to be treated and reused aboard marine vessels for toilet flushing.

This unique marine application presented many challenges not seen in municipal or industrial wastewater applications. With a marine vessel's constant movement, small space requirements, variable ship personnel, flow surges and operator skill level, a traditional primary, secondary and even tertiary treatment process would not work. The first prototype was installed aboard the river towboat M/V Missouri in 1969. The success of the unit sparked full production of what is now known as MarineFAST® (availble through Scienco/FAST, Inc) in 1973. The success of the FAST process sparked engineering efforts for development of land-based FAST treatment plants that would provide the very same benefits: a robust, stable treatment process, small footprint and very little need for operator attention.

From this interesting beginning, the FAST technology has been engineered into many product lines; all designed around the same fixed activated sludge treatment process. FAST products can now be seen operating quietly in residential, commercial, municipal, industrial and marine applications around the globe.

Technical Specifications

Materials of construction: Made with 100% corrosion resistant materials and contains post-consumer recycled materials.

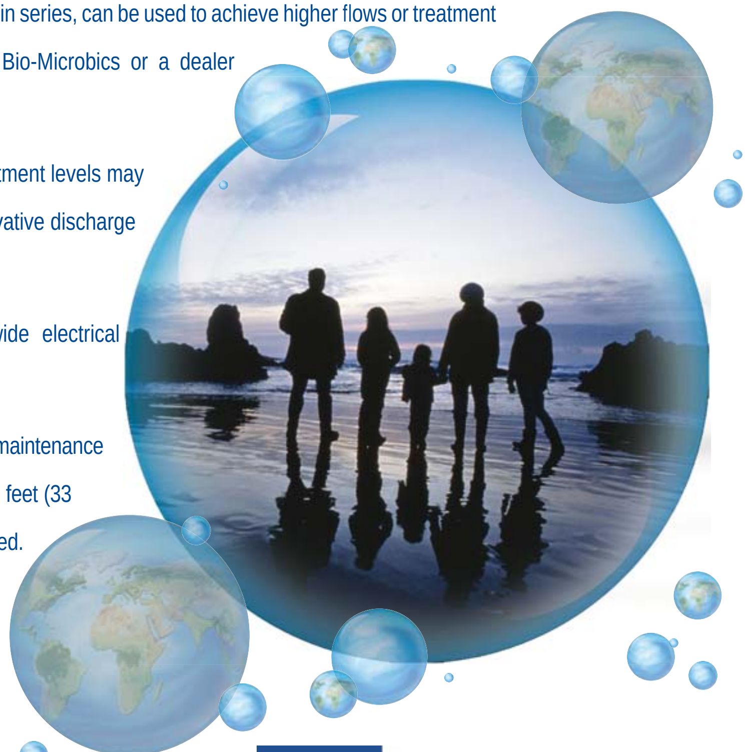
FAST® Installation: FAST systems are mounted inside tanks in above ground or below ground applications. Tanks can be made from concrete, fiberglass, steel or plastic materials. Please consult product specifications for specific tank recommendations. Always check local regulations before installing or altering a wastewater system. Contact Bio-Microbics or a dealer near you for more information on the availability of proper tankage in your area.

Capacity: FAST systems are available in several convenient, affordable sizes and configurations. Multiple FAST modules, in parallel or in series, can be used to achieve higher flows or treatment capacities. Please contact Bio-Microbics or a dealer near you for more information on the FAST system that's right for your application.

Dispersal Options: Check your local regulations. The extraordinarily high treatment levels may allow reductions in drain field areas, use of treated water for irrigation or other innovative discharge methods.

Power required: Electrical components are available to meet all worldwide electrical specifications (volt/phase/frequency).

Maintenance Requirements: Once installed, FAST systems are virtually maintenance free. The only moving part in the system is an above ground blower placed up to 100 feet (33 m) away. Periodic review of electronic components and residual levels recommended. Residuals will need to be removed when appropriate.



Typical Applications:

- Single-family homes
- Clustered subdivisions
- Municipalities
- Restaurants
- Schools
- RV & Mobile-home parks
- Office parks
- Resorts and hotels
- Golf courses
- Shopping centers
- Grocery stores
- Food & Beverage
- Wineries
- Petrochemical/Chemical
- Aerobic polishing
- Pharmaceutical
- Luxury Yachts
- Tug & Work boats
- Offshore vessels
- Tankers
- Aircraft carriers
- Cruise ships
- Military facilities
- Mobile Worker Camps

BIO-MICROBICS® INCORPORATED

Better Water. Better World.™

Bio-Microbics, Inc.
8450 Cole Pkwy • Shawnee, KS 66227
Ph: 913.422.0707 • Fax: 913.422.0808
e-mail: **sales@biomicrobics.com**

800.753.FAST (3278) • www.biomicrobics.com

FAST® Certifications Include:

- US Electrical System • Underwriters Laboratories (UL) • US Coast Guard • International Maritime Organization (IMO)
- Canadian Standards Association (CSA) • Canadian Great Lakes (CGL) • UK Department of Trade • European Union (CE)
- European Electrical Systems (& Tropical Certification) • Royal Australian Navy • Australian Department of Transportation
- Saudi Arabian Standards Organization (SASSO) • NSF/ANSI Standard 40 & 245 for MicroFAST 0.5, 0.75, 0.9, and 1.5
- US Environmental Protection Agency (EPA) Environmental Technology Verification (ETV) for RetroFAST .250 and .375

PINNACLE ENVIRONMENTAL TECHNOLOGIES INC.
22765 - A Fraser Highway, Langley, BC, Canada

Telephone: 604.514.7555
Toll Free: 866.514.7555
Fax: 604.514.7595
Mailing Address: P.O. Box 3070
Langley, BC, Canada, V3A 4R3

www.peti.ca

NOMADIC™
MOBILE SEWAGE WASTEWATER TREATMENT SYSTEM

DS Series	# of Persons
NOMADIC DS 10	10
NOMADIC DS 15	15
NOMADIC DS 20	20
NOMADIC DS 25	25
HS Series	
NOMADIC HS 21/25	25
NOMADIC HS 26/50	50
NOMADIC HS 51/75	75
NOMADIC HS 100	100
NOMADIC HS 150	150
NOMADIC HS 250	250
NOMADIC HS 500	500
NOMADIC HS 750	750
ASCO$_2$R Series	
ASCO$_2$R Series 1000 - 2500	>1000

NOMADIC™ DS and HS Series have, at the core of the treatment process, the **Fixed Activated Sludge Treatment System** known as FAST® and as available from Bio-Microbics Inc.

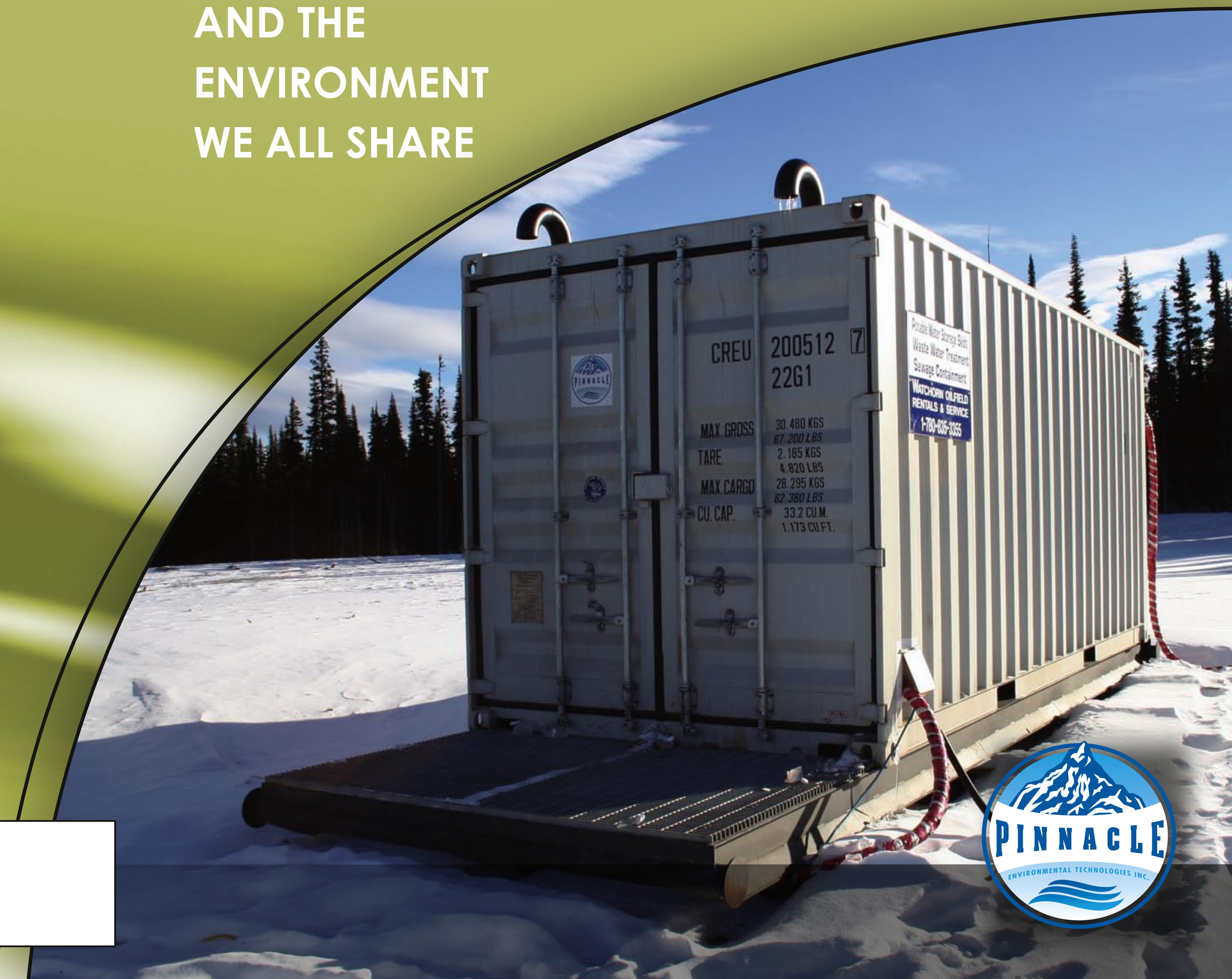
Pinnacle Environmental Technologies Inc. is the exclusive Canadian Distributor of the FAST® system and employs the technology in a wide variety of designs and settings to provide solutions for sewage wastewater treatment across Canada and offshore.

The NOMADIC™ DS and HS Series are a tested and true result of the Pinnacle design to meet the specific needs of the mobile work camp market, satisfy regulatory requirements and provide easy maintenance at an affordable cost.

NOMADIC™

MOBILE SEWAGE WASTEWATER TREATMENT SYSTEM

TO PROTECT PUBLIC HEALTH AND THE ENVIRONMENT WE ALL SHARE



NOMADIC™
MOBILE SEWAGE WASTEWATER TREATMENT SYSTEM

Mobile and Portable Systems

The NOMADIC™ series is designed for mobile work camps and disaster relief. The systems are available for a variety of applications such as mobile, portable in permanent arrangements, semi-permanent or short-term temporary installations.

The NOMADIC™ system design takes into account the following design considerations:

- High-strength sewage wastewater characteristics
- Fats, oils and greases from the centralized kitchen works
- Power availability
- Fresh water supply and characteristics
- Cold weather climate conditions
- High altitude conditions
- Above-ground, free-standing arrangements
  – Outdoor installation
  – Indoor installation
- In-ground installations
- Pump and dosing packages
  – pumping into the system
  – pumping or dosing within the system
  – pumping or dosing to the discharge point
- Flow equalization
- Pre-settling and trash collector chamber
- Effluent disinfection
- Automated grease interceptor

900 Person Siberia, Russia Mining Camp

NOMADIC™ DS Series

NOMADIC™ DS Series are for work camps up to 25 persons and which do not utilize a commericial-grade kitchen.

Design and Build

Our knowledgeable and experienced design team consult with you to design and build the system that meets specific unique needs and requirements. Largest system, at time of printing, is for 1,800 person camp.

Standard Series

Available in 3 series.

- NOMADIC™ DS
- NOMADIC™ HS
- NOMADIC™ ASCO$_2$R

Emergency Response/Disaster Relief

The NOMADIC™ system is easily portable for fast mobilization to areas that need immediate response to a disaster or crisis. Connection to power supply is simple. Effluent quality is suitable for safe and clean discharge even into surface water if required.

Applications

- Forestry
- Mining
- Gas and Oil Drilling
- Remote Fishing Resorts
- Fire Fighting Camps

Installation Locations

- Northern Alberta
- Northern Canada
- United States of America
- Siberia, Russia
- USA-FEMA

Benefits

- High treatment levels
- Low sludge production
- Low maintenance skill level
- Performance pure and simple
- Rapid deployment

Rugged Construction

Heavy gauge steel construction with skid mounts and roll bars allows for multiple moves and long term use.

NOMADIC™ DS Model

NOMADIC™ Work Camp

Systems for Industry on the Move and Sanitation for Disaster Relief

NOMADIC™
MOBILE SEWAGE WASTEWATER TREATMENT SYSTEM

peti@canada.com

www.peti.ca

United States
Environmental Protection
Agency

Wastewater Technology Fact Sheet

Facultative Lagoons

DESCRIPTION

Facultative waste stabilization ponds, sometimes referred to as lagoons or ponds, are frequently used to treat municipal and industrial wastewater in the United States. The technology associated with facultative lagoons has been in widespread use in the United States for at least 90 years, with more than 7,000 facultative lagoons in operation today. These earthen lagoons are usually 1.2 to 2.4 m (4 to 8 feet) in depth and are not mechanically mixed or aerated. The layer of water near the surface contains dissolved oxygen due to atmospheric reaeration and algal respiration, a condition that supports aerobic and facultative organisms. The bottom layer of the lagoon includes sludge deposits and supports anaerobic organisms. The intermediate anoxic layer, termed the facultative zone, ranges from aerobic near the top to anaerobic at the bottom. These layers may persist for long periods due to temperature-induced water-density variations. Inversions can occur in the spring and fall when the surface water layer may have a higher density than lower layers due to temperature fluctuations. This higher density water sinks during these unstable periods, creates turbidity, and produces objectionable odors.

The presence of algae in the aerobic and facultative zones is essential to the successful performance of facultative ponds. In sunlight, the algal cells utilize CO_2 from the water and release O_2 produced from photosynthesis. On warm, sunny days, the oxygen concentration in the surface water can exceed saturation levels. Conversely, oxygen levels are decreased at night. In addition, the pH of the near surface water can exceed 10 due to the intense use of CO_2 by algae, creating conditions favorable for ammonia removal via volatilization. This photosynthetic activity occurs on a diurnal basis, causing both oxygen and pH levels to shift from a maximum in daylight hours to a minimum at night.

The oxygen, produced by algae and surface reaeration, is used by aerobic and facultative bacteria to stabilize organic material in the upper layer of water. Anaerobic fermentation is the dominant activity in the bottom layer in the lagoon. In cold climates, oxygenation and fermentation reaction rates are significantly reduced during the winter and early spring and effluent quality may be reduced to the equivalent of primary effluent when an ice cover persists on the water surface. As a result, many states in the northern United States and Canada prohibit discharge from facultative lagoons during the winter.

Although the facultative lagoon concept is land intensive, especially in northern climates, it offers a reliable and easy-to-operate process that is attractive to small, rural communities.

Common Modifications

A common operational modification to facultative lagoons is the "controlled discharge" mode, where pond discharge is prohibited during the winter months in cold climates and/or during peak algal growth periods in the summer. In this approach, each cell in the system is isolated, then discharged sequentially. A similar modification, the “hydrograph controlled release” (HCR), retains liquid in the pond until flow volume and conditions in the receiving stream are adequate for discharge.

A recently developed physical modification uses plastic curtains, supported by floats and anchored to the bottom, to divide lagoons into multiple cells and/or to serve as baffles to improve hydraulic conditions. Another recent development uses a floating plastic grid to support the growth of duckweed (*Lemna* sp.) plants on the surface of the final cell(s) in the lagoon system, which restricts the penetration of light and thus reduces algae (with sufficient detention time $\geq$ 20 days), improving the final effluent quality.

APPLICABILITY

The concept is well suited for rural communities and industries where land costs are not a limiting factor. Facultative lagoons can be used to treat raw, screened, or primary settled municipal wastewater and biodegradable industrial wastewaters.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of facultative lagoons are listed below:

Advantages

Moderately effective in removing settleable solids, BOD, pathogens, fecal coliform, and ammonia.

Easy to operate.

Require little energy, with systems designed to operate with gravity flow.

The quantity of removed material will be relatively small compared to other secondary treatment processes.

Disadvantages

Settled sludges and inert material require periodic removal.

Difficult to control or predict ammonia levels in effluent.

Sludge accumulation will be higher in cold climates due to reduced microbial activity.

Mosquitos and similar insect vectors can be a problem if emergent vegetation is not controlled.

Requires relatively large areas of land.

Strong odors occur when the aerobic blanket disappears and during spring and fall lagoon turnovers.

Burrowing animals may be a problem.

DESIGN CRITERIA

Waste stabilization pond systems are simplistic in appearance, however, the reactions are as complicated as any other treatment process. Typical equipment used in facultative lagoons includes lining systems to control seepage to groundwater (if needed), inlet and outlet structures, hydraulic controls, floating dividers, and baffles. Many existing facultative lagoons are large, single-cell systems with the inlet constructed near the center of the cell. This configuration can result in short-circuiting and ineffective use of the design volume of the system. A multiple-cell system with at least three cells in series is recommended, with appropriate inlet and outlet structures to maximize effectiveness of the design volume. Most states have design criteria that specify the areal organic loading (kg/ha/d or lbs/acre/d) and/or the hydraulic residence time. Typical organic loading values range from 15 to 80 kg/ha/d (13 to 71 lbs/acre/d). Typical detention times range from 20 to 180 days depending on the location. Detention times can approach 200 days in northern climates where discharge restrictions prevail. Effluent biochemical oxygen demand (BOD) $\leq$ 30 mg/L can usually be achieved, while effluent TSS may range from $\leq$ 30 mg/L to more than 100 mg/L, depending on the algal concentrations and design of discharge structures.

A number of empirical and rational models exist for the design of simple and series constructed facultative lagoons. These include first-order plug flow, first-order complete mix, and models proposed by Gloyna, Marais, Oswald, and Thirumurthi. None of these has been shown to be clearly superior to the others. All provide a reasonable design as long as the basis for the formula is understood, proper parameters are selected, and the hydraulic detention and sludge retention characteristics of the system are known. This last element is critical because short circuiting in a poorly designed cell can result in detention time of 40 percent or less than the theoretical design value.

PERFORMANCE

Overall, facultative lagoon systems are simple to operate, but only partially reliable in performance. BOD_5 removal can range up to 95 percent. However, the TSS range may exceed 150 mg/L. Removal of ammonia nitrogen can be significant (up to 80 percent), depending on temperature, pH, and detention time in the system. However, the removal cannot be sustained over the winter season. Due to precipitation reactions occurring simultaneously with the daily high pH (alkaline) conditions in the lagoon, approximately 50 percent phosphorus removal can be expected. Removal of pathogens and coliforms can be effective, depending on temperature and detention time.

Limitations

Limitations may include the inability of the process to meet a 30 mg/L limit for TSS due to the presence of algae in the effluent, particularly during warm weather, and not meeting effluent criteria consistently throughout the year. In cold climates, low temperatures and ice formation will limit process efficiency during the winter. Odors may be a problem in the spring and fall during periods of excessive algal blooms and unfavorable weather conditions.

OPERATION AND MAINTENANCE

Most facultative lagoons are designed to operate by gravity flow. The system is not maintenance intensive and power costs are minimal because pumps and other electrically operated devices may not be required. Although some analytical work is essential to ensure proper operation, an extensive sampling and monitoring program is usually not necessary. In addition, earthen structures used as impoundments must be inspected for rodent damage.

COSTS

Cost information for facultative lagoons varies significantly. Construction costs include cost of the land, excavation, grading, berm construction, and inlet and outlet structures. If the soil is permeable, an additional cost for lining the lagoon should be considered.

REFERENCES

Other Related Fact Sheets

Other EPA Fact Sheets can be found at the following web address:

http://ww.epa.gov/owm/mtb/mtbfact.htm

1. Middlebrooks, E.J., et al., 1982. *Wastewater Stabilization Lagoon Design, Performance and Upgrading*, McMillan Publishing Co., New York, NY.

2. Pano, A. and Middlebrooks, E.T., 1982. Ammonia Nitrogen Removal in Facultative Wastewater Stabilization Ponds. Water Pollution Control Federation Journal, 54 (4) 344-351.

3. Reed, S.C., et al., 1995, 2nd Ed. *Natural Systems for Waste Management and Treatment*, McGraw Hill Book Co., New York, NY.

4. Reed, S.C., 1985. *Nitrogen Removal in Wastewater Stabilization Ponds*, Water Pollution Control Federation Journal. 57(1)39-45.

5. U.S. EPA, 1983. *Design Manual - Municipal Wastewater Stabilization Ponds*, EPA-625/1-83-015, US EPA CERI. Cincinnati, OH.

6. WPCF, 1990. MOP FD-16, *Natural Systems for Wastewater Treatment*, Water Pollution Control Federation, Alexandria, VA.

ADDITIONAL INFORMATION

Richard H. Bowman, P.E.
West Slope Supervisor
Colorado Department of Public Health and Environment
Water Quality Control Division
222 South 6th Street, Room 232
Grand Junction, CO 81502

Earnest F. Gloyna, P.E.
Consulting Engineer
701 Brazos, Suite 550
Austin, TX 78701

E. Joe Middlebrooks, Ph.D., P.E. DEE
Environmental Engineering Consultant
360 Blackhawk Lane
Lafayette, CO 80026-9392

Gordon F. Pearson
Vice President
International Ecological Systems & Services, IESS
P.O. Box 21240
B-1 Oak Park Plaza
Hilton Head, SC 29925

Sherwood Reed
Principal
Environmental Engineering Consultants (EEC)
50 Butternut Road
Norwich, VT 05055

Leroy C. Reid, Jr., Ph.D
1273 Annapolis Drive
Anchorage, AK 99508-4307

Office of Water
EPA 832-F-02-014
September 2002

For more information contact:

Municipal Technology Branch
U.S. EPA
1200 Pennsylvania Ave., NW
Mail Code 4201M

★ 2002 ★
THE YEAR OF
CLEAN WATER
Celebration & Recommitment

OWM MTB
Excellence in compliance through optimal technical solutions
MUNICIPAL TECHNOLOGY BRANCH

APPENDIX C

DETAILED LIFECYCLE COST ESTIMATES

	Item	Base Cost	Transportation Cost	Installation Cost	Life Expectancy (Years)	NPV after 20 Years	NPV after 40 Years
FAST System	FAST system	$390,537	$75,200	$45,600	40	$511,337	$511,337
	1.5 hp air blower	$2,000	$410	$0	10	$1,985	$4,965
	5 hp air blower	$3,000	$410	$0	10	$2,808	$7,025
	3 pumps (0.5 hp)	$3,000	$410	$0	10	$2,808	$7,025
	Equalization basin	$5,000	$6,300	$2,500	40	$13,800	$13,800
	2 grease interceptors	$14,000	$410	$0	10	$11,867	$29,687
	Building with insulation	$107,500	$75,200	$111,750	40	$294,450	$294,450
	3 oil heaters	$19,500	$6,300	$1,250	10	$22,276	$55,727
	Foundation and flooring	$114,750	$68,900	$45,000	40	$228,650	$228,650
	Piping	$31,500	$6,300	$25,000	40	$62,800	$62,800
	Electrical and plumbing connections	$5,000	$50,000	$20,000	40	$75,000	$75,000
	Design fee and geotechnical inspection	$70,000	$100,000	$0	not applicable	$170,000	$170,000
	Power consumption for building heating	$2,758	$0	$0	1	$45,268	$75,968
	Power consumption for equipment	$24,090	$0	$0	1	$395,401	$663,549
	Power consumption for heat trace for piping	$3,581	$0	$0	1	$58,777	$98,637
	Construction management cost (15%)	$205,567	$50,000	$0	not applicable	$255,567	$255,567
	Contingency (35%)	$551,605	$0	$0	not applicable	$551,605	$551,605
					TOTAL	**$2,704,399**	**$3,105,792**

	Item	Base Cost	Transportation Cost	Installation Cost	Life Expectancy (Years)	NPV after 20 Years	NPV after 40 Years
Waterloo Biofilter	Biofilter system	$250,000	$75,200	$45,600	40	$370,800	$370,800
	Biofilter media	$26,000	$6,300	$0	20	$0	$21,905
	3 pumps (1 hp)	$3,000	$410	$0	10	$2,808	$7,025
	Air fan	$5,000	$410	$0	10	$4,455	$11,145
	2 grease interceptors	$14,000	$410	$0	10	$11,867	$29,687
	Equalization basin	$5,000	$6,300	$2,500	40	$13,800	$13,800
	Building with insulation	$107,500	$75,200	$111,750	40	$294,450	$294,450
	3 oil heaters	$19,500	$6,300	$1,250	10	$22,276	$55,727
	Foundation	$114,750	$68,900	$45,000	40	$228,650	$228,650
	Piping	$31,500	$56,300	$25,000	40	$112,800	$112,800
	Electrical and plumbing connections	$5,000	$100,000	$20,000	40	$125,000	$125,000
	Design fee and geotechnical inspection	$70,000	$0	$0	not applicable	$70,000	$70,000
	Power consumption for building heating	$7,222	$0	$0	1	$118,538	$198,927
	Power consumption for equipment	$1,275	$0	$0	1	$20,927	$35,119
	Power consumption for heat trace for piping	$3,581	$0	$0	1	$58,777	$98,637
	Construction management cost (15%)	$180,474	$50,000	$0	not applicable	$230,474	$230,474
	Contingency (35%)	$484,272	$0	$0	not applicable	$484,272	$484,272
					TOTAL	**$2,169,894**	**$2,388,418**

New Lagoon Option 1	Item	Base Cost	Transportation Cost	Installation Cost	Life Expectancy (Years)	NPV after 20 Years	NPV after 40 Years
	2 cell lagoon	$0	$311,600	$805,000	100	$1,116,600	$1,116,600
	Liner	$55,215	$62,600	$34,000	100	$151,815	$151,815
	2 pumps	$5,000	$410	$0	10	$9,865	$11,145
	Lagoon berm repair	$0	$0	$12,000	5	$29,740	$58,046
	Piping	$70,000	$6,300	$25,000	40	$101,300	$101,300
	Extra piping cost for further location	$70,000	$6,300	$25,000	40	$101,300	$101,300
	Electrical and plumbing connections	$5,000	$50,000	$20,000	40	$75,000	$75,000
	Design fee and geotechnical inspection	$100,000	$100,000	$0	not applicable	$200,000	$200,000
	Power consumption for pumps	$1,200	$0	$0	1	$21,272	$33,053
	Power consumption for heat trace for piping	$3,438	$0	$0	1	$60,948	$94,704
	Power consumption for heat tracing for extra piping	$3,438	$0	$0	1	$60,948	$94,704
	Construction management cost (15%)	$268,714	$50,000	$0	not applicable	$318,714	$318,714
	Contingency (35%)	$721,049	$0	$0	not applicable	$721,049	$721,049
					TOTAL	**$2,968,549**	**$3,077,430**

New Lagoon Option 2	Item	Base Cost	Transportation Cost	Installation Cost	Life Expectancy (Years)	NPV after 20 Years	NPV after 40 Years
	2 cell lagoon	$0	$311,600	$805,000	100	$1,116,600	$1,116,600
	Liner	$55,215	$62,600	$34,000	100	$151,815	$151,815
	2 pumps	$5,000	$410	$0	10	$9,865	$11,145
	Lagoon berm repair	$0	$0	$12,000	5	$29,740	$58,046
	Piping	$150,000	$12,600	$40,000	40	$202,600	$202,600
	Extra piping cost for further location	$150,000	$12,600	$40,000	41	$202,600	$202,600
	Electrical and plumbing connections	$5,000	$50,000	$20,000	40	$75,000	$75,000
	Design fee and geotechnical inspection	$100,000	$100,000	$0	40	$200,000	$200,000
	Power consumption for pumps	$1,200	$0	$0	1	$21,272	$33,053
	Power consumption for heat trace for piping	$4,679	$0	$0	1	$82,948	$128,890
	Power consumption for heat trace for piping	$4,679	$0	$0	1	$82,948	$128,890
	Construction management cost (15%)	$305,104	$50,000	$0	not applicable	$355,104	$355,104
	Contingency (35%)	$818,695	$0	$0	not applicable	$818,695	$818,695
					TOTAL	**$3,349,187**	**$3,482,438**

At Golder Associates we strive to be the most respected global group of companies specializing in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organizational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

Africa	+ 27 11 254 4800
Asia	+ 852 2562 3658
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
32 Steacie Drive
Kanata, Ontario, K2K 2A9
Canada
T: +1 (613) 592 9600